Using The Glass and Rubber waste as Sustainable Materials to Prepare Foamed Concrete with Improved Properties

Awham M.Hameed\textsuperscript{1} and Ruqaya F. Hamada\textsuperscript{1}
\textsuperscript{1}Applied Sciences Department, University of Technology, Baghdad, Iraq
Email: 100155@uotechnology.edu.iq , 100298@student.uotechnology.edu.iq

Abstract. Building materials and technologies in the world have evolved in line with the new requirements for sustainable construction, which have spread throughout the world to reduce damage to the environment and reduce energy consumption, and rely on renewable energy sources to ensure the rights of future generations of environmental resources. This paper aims at identifying the possibility of using recycled materials such as glass powder (windows glass) and rubber wastes (gloves) to produce the foamed concrete as a substitute filler for cement. The samples of foamed were prepared by using two different percentages of foam agent (FA). The use of gloves rubber waste (GV) and glass powder (GP) in this study could enhance the strength by filling the voids in foam concrete. The amount of rubber waste and glass powder used as additive in foam concrete are 1, 3, 5 wt. % of rubber waste and 1, 0.7 wt. % of glass powder. The mix design was set to achieve a target density of 1600kg/m$^3$. The results showed that the optimum compressive strength value is 10.26MPa of water cured sample at 0.8wt. %FA and 0.7wt.%GP but it is 9.26MPa of air cured sample at 1wt.%FA and 0.7wt.%GP. Flexural strength values were 3.79MPa, 3.87MPa of water and air cured samples at 0.8%FA and 0.7%GP while the splitting tensile strength was increased to 1.71MPa, 1.52MPa in both curing methods for the same percentages. The bulk density was decreased with increasing of glass powder and foam agent content. It is found that the best thermal conductivity value is 0.4096(W/m.°c) to achieve appropriate insulation property of the sample contained 1wt. % of each FA and GP. All of the studied properties were increased after adding 1wt. % of gloves rubber waste (GV).

Key words: Foamed concrete, construction materials, glass waste, rubber waste, thermal conductivity.

1. Introduction
Sustainable foam concrete is concrete that is more environmentally friendly, all the parameters of the green building index and one of the methods adopted in this type of concrete is the use of sustainable building materials that are characterized by the efficiency of thermal and acoustic insulation, lightweight and cost saving, and depend in their manufacture on reducing consumption of raw materials, energy and reduce pollutants, emissions and residues resulting from it during the life cycle of the building in a way that reduces damage to the environment, ecosystems and human health, as well as emphasizing the benefit of local materials being the least each In terms of transportation and raw materials. This architecture also seeks to take advantage of technological development with environmentally friendly technologies in building systems to harmonize with the new requirements for construction and operate in accordance with the principle of optimal utilization of knowledge and scientific progress to achieve sustainable building operations [1, 2]. Glass waste is a major component of the solid waste stream in many countries. They can be found in many shapes, including container glass, flat glass such as windows, lamp glass, and cathode ray tube glass. Usually, wasted glass does
not cause any harm to the environment in any way due to its non-degradable nature, but if disposed of incorrectly it may cause harm to both humans and animals [3]. However, glass is a 100% recyclable material with high performance and unique aesthetic properties, which makes it suitable for widespread use. It is only appropriate to reduce the glass to powdered form waste glass powder (GP), in order to obtain more satisfactory results [4].

Another important effort taken by to ensure sustainable management rubber wastes are through reuse, recycling, recovery, and pyrolysis. Reused the rubber (i.e: gloves, tyros) simply by retreading and reuse back. Rubber also held another valuable characteristic such as able to dampen or reduce vibration better-wet grip, relatively resistance to gas and water permeability and reduced swelling. Recycling of waste rubber includes utilizing into various applications such as incorporate into matrixes such as concrete and used for civil engineering or being manufacture into brand new products such as athletic tracks and playground surface [5, 6].

Abdullah 2017 [7] prepared foam concrete incorporating amount of rubber powder added as filler in foamed concrete are(0%, 3%, 6%, 9% and 12%). prepared about of 15 foam concrete cubes and 15 foam concrete cylinders with difference percentages of rubber powder in order to study compressive and splitting tensile strength. The experiments results shown the compressive and splitting tensile strengths for foamed concrete containing rubber are greater compared to foamed concrete without rubber powder. The addition of 9% of rubber powder brought a significant increase for compressive strength and tensile strength of 122% and 43%, respectively, as compared to foamed concrete without rubber powder. Based on the results, it noticed the optimum percentage of rubber 9% for the improve properties compressive and tensile strength for foamed concrete.

Qasim S. Khan et al. 2019[8] investigated the potential of the use of recycled glass powder. The recycled glass powder added (20%, 40%) replacement of cement ratio, water to cement ratio (w/c=0.5) and volume of foam (0.45%, 0.43%, 0.39%, 0.35%, 0.32%). The experimental results showed that density and compressive strength at 20% replacement cement of recycles glass powder is better than 40% recycled glass powder.

This research aims to fabricate foamed concrete with the replacement of cement with gloves rubber waste, glass windows powder as sustainable materials. The research focuses on the recycling for these waste and nature protection from its negative effects. This paper applies the light on some physical and mechanical properties of the foamed concrete before and after these additives.

2. Experimental Work

2.1 Materials

2.1.1 Cement

Ordinary Portland cement (Type1) fabricated by (Lafarge company/ Bazian) commercial recognized as (Krasta) was utilized during the research work. The properties of cement used according to Iraqi Standards No.5/1984.

2.1.2 Sand

Sand was used research work is known as (Al- Ekhaider). Sieve analysis fine aggregate shown in table 1 and gradation curve shown in figure 1. The physical characteristic of fine aggregate, according to Limits of the Iraqi standards No.45/1984, specific gravity is 2.6, bulk density 1730 Kg/m³; sulfate content 0.33%, absorption 2%
Table 1. Sieve analysis of sand.

| Sieve size (mm) | Cumulative passing % | Limited of I.Q.S No.45/1984,zone(4) |
|-----------------|-----------------------|-------------------------------------|
| 10              | 100                   | 100                                 |
| 4.75            | 95                    | 95-100                              |
| 2.36            | 86                    | 95-100                              |
| 1.18            | 77                    | 90-100                              |
| 0.6             | 59                    | 80-100                              |
| 0.3             | 30                    | 15-50                               |
| 0.15            | 13                    | 0-15                                |

Figure 1. Grading curve of sand.

2.1.3 Water
Ordinary tap water was utilized for mixing and curing for each concrete mix through experimental work.

2.1.4 Foam Agent
Foam agent type (EABSSOC) from Swiss Chemistry Factory was utilized in this work according to ASTM C869 – 2016 [9]. It was used to foam agents are made to produce stable foam (air bubbles) that resist applied forces when mixing, casting and curing of foam concrete. Produce lightweight concrete by entraining a controlled amount of air bubbles to concrete mix. The table 2. Shows the Properties of an EABSSOC foaming agent [10].

Table 2. Properties of foaming agent (EABSSOC).

| Properties                  | Description                                           |
|-----------------------------|-------------------------------------------------------|
| Appearance                  | Translucent, pale brown liquid                        |
| Specific gravity            | 1.02                                                  |
| Water Solubility            | Infinite                                              |
| Dosage rate                 | 0.3-0.6 liters per m³ of foamed concrete produced     |
| PH                          | 6.7 in solution                                       |
| Freezing point              | -3 to -5 Recovered fully after freezing               |
| Chloride Content            | Less than 0.0001 parts                                |

2.1.5 Glass powder (GP)
Glass powder used in this study are obtained from flat or window glass and crushed it into glass powder by using mill it as shown in figure 2. The particle size of glass powder ranged from
(≥1.18mm-≤300μm) the chemical analysis of this material obtained from x-ray analysis is shown in the table 3.

![Glass powder (GP)](image)

*Figure 2. Glass powder (GP).*

*The glass waste was crushed at the University of Technology in the ceramic laboratory

| Analysis  | Results test% |
|-----------|---------------|
| SiO₂      | 84.627        |
| CaO       | 8.192         |
| Al₂O₃     | 5.572         |
| K₂O       | 1.237         |
| Fe₂O₃     | 0.242         |
| TiO₂      | 0.061         |
| SO₃       | 0.029         |
| MnO       | 0.012         |
| ZrO₂      | 0.011         |
| CuO       | 0.007         |
| SrO       | 0.005         |
| V₂O₅      | 0.005         |

*Chemical test was carried out in National Center for Laboratory and Structural Research Baghdad Central laboratory

2.1.6 Rubber gloves Waste

About the waste gloves used in this research, it is important to show that the steps of treatment of recycled rubber gloves are the (collecting, wash, drying and then cutting into small size). The thickness of these chopped gloves nearly (25.4) μm which was measured by using micrometer tool, the show in Figure 3 and the chemical analysis of this material obtained from the FTIR analysis the purpose from FTIR test is to identify the chemical groups of rubber waste gloves as showed in Figure 4.

![Recycled rubber gloves](image)
3. Preparation of samples

3.1 Mixing of concrete
For preparing the foam concrete into three steps and Percentage of materials shown in table 4. The step1 prepare the foam concrete (FC) the dry materials (sand and cement) ratio 1:2 were mixed for two minutes, the w/c different ratio according to the mixture, then the two thirds water added to dry materials were mixture 2 minutes. Step2 remaining water add to the foam agent the mixture by hand machine for 4 minutes to become heavy white foam this method called pre-foamed, then add to wet mixture (cement, sand, water) and mixing 2 minutes. Step3 the mixture to obtain a homogenous mortar.

| Type | Cement : Sand Ratio | Water/cement (w/c) | Foam agent(FA) wt.% | Glass powder(GP) wt.% | Gloves rubber waste(GV) wt.% | Target density kg/m³ |
|------|---------------------|--------------------|---------------------|-----------------------|----------------------------|----------------------|
| RC   | 1:2                 | 0.50               | -                   | -                     | -                          | 1600                 |
| FC   | 1:2                 | 0.45               | 1, 0.8              | 1, 0.7                | -                          | 1600                 |
| FC   | 1:2                 | 0.47               | 0.8                 | -                     | 1, 3, 5                    | 1600                 |

*RC: Reference (cement mortar), FC: Foam concrete.

3.2 Molding, Compaction and Curing of the Specimens
Before the molding, all molds were oiled carefully to be prepared for casting the fresh mortar. The foamed concrete (FC) samples were cast into three layers, each layer was compacted by rod after that the samples were wet cured at room temperature than removed from the molds after 24 hours and cured into tab water containers for ages 7, 14, 28 days.

4. Test Procedures

4.1 Bulk density
The bulk density test was determined according to the ASTM C109 standards [11]. The bulk density tested at age’s time 3, 7, 14, and 28 days. This test was calculated by dividing the total mass of concrete on the volume of cubic sample.

\[ \rho = \frac{m}{V} \]  

(1)
Where: $\rho$: Bulk density of the sample, $m$: Mass of the sample, $V$: Volume of sample.

### 4.2 Compressive strength

The (50 mm) cubic specimens were tested under compression according to ASTM C109 [11]. (CONTROLS) test model 065-10019/B machine of 250kN load capacity was performed. The test was conducted at age's times 7, 14 and 28 days. The compressive strength of this sample was determined by dividing the ultimate load applied to the samples throughout the test to achieve the final failure by the average cross - sectional area of the samples.

\[
\text{Compressive Strength} = \frac{F}{A} \quad (2)
\]

Where: $F$: Force (N), $A$: the cross sectional area (mm$^2$).

### 4.3 Flexural Strength

The 40x40x160mm prism specimens were tested under flexural in conformity with UNIE196-1 specifications. A (CONTROLS) test model 065-10019/B machine of 250kN load strength was carried out three point. Flexural strength samples test was conducted at ages time 7, 14 and 28 days test was performed to determine the flexural strength calculate by applying of the equation

\[
\text{Flexural Strength (F.S)} = \frac{3P L}{2b (d^2)} \quad (3)
\]

Where: $P$: applied load (N), $L$: The distance between two points (mm), $b$: width of prism sample (mm), $d$: depth of prism sample (mm).

### 4.4 Splitting tensile strength

A cylindrical concrete sample is placed with its horizontal axis between two spans of tensile testing machine. The splitting tensile strength test was done according to ASTM C496-86 standard [12]. Splitting tensile strength samples test was conducted at curing time 7, 14 and 28 days and then load was applied continuously up to obtain the failure by using a standard testing machine with capacity 2500 KN.

\[
T. S = \frac{2P}{\pi D L} \quad (4)
\]

where:

T.S: splitting tensile strength (MPa), $P$: Max load (N), $D$: diameter of sample (mm), $L$: length of sample (mm).

### 4.5 Thermal conductivity

The thermal conductivity test was carried out according to B.S 874-73. A special mold was prepared to produce the required specimen with diameter 40 mm and 10 mm thickness. Lee’s disk device was used for determining the thermal conductivity (K).

5. Results and discussion

5.1 Bulk Density

Figures 5 a, b shows that the results of bulk density of foam concrete contained glass powder of different percentages (1 and 0.7wt.%) for the two amounts of foam agent (1 and 0.8wt.%). It can be observed that when 1wt.% (GP) was added to foam mortar that contains 1wt.% of foam agent, the bulk density increases with increasing glass powder (GP) content and decrease with reduce glass powder amount to 0.7wt.% in water curing but in air curing the bulk density value increased to the range 1.65g/cm$^3$ for the lower amount glass powder, while the foam mortar which contains 0.8wt.% foam agent with 1 and 0.7wt.% (GP) has bulk density decreased with increasing of glass powder content in water curing other than that of air curing at 28days. Figure 6 a, b illustrates the effect of gloves rubber waste percentage (1, 3, 5 wt.%) added to the mix concrete contained 0.8wt. % foam agent on the bulk density. The results shown of 1 and 5wt.% (GV) demonstrate the increasing of bulk density under water and air curing with ages time (3, 7, 14, 28 days) and while it decreases to 1.86g/cm$^3$, 1.55g/cm$^3$ of both curing methods when 3wt.% of GV was added for the age 28 days of curing.
Figure 5. Bulk density of foamed concrete contained 1%, 0.8% of foam agent (FA) and different percentages of glass powder (GP) cured in (a) water (b) air for 3, 7, 14, 28 days.

Figure 6. Bulk density of foamed concrete contained 0.8% of foam agent (FA) and different percentages of gloves rubber waste (GV) cured in (a) water, (b) air for 3, 7, 14, 28 days.

5.2 Compressive Strength
Compressive strength of the foam concrete increasing with increase curing age as given in figure 7 a, b. It is shown when glass powder (GP) content equal to 1wt.% with different amount 1 and 0.8wt. % of foam agent lead to decrease the compressive strength value to (4.5 MPa), (4.49 MPa) of each curing method at 1wt%FA+1wt%GP. When foam agent was decreased to 0.8wt. % with same percentage of (GP), it is noticed that the compressive strength was increased to (8.90 MPa), (7 MPa) after water and air curing. The decreasing of compressive strength with increasing glass powder percentage may be due to some inherent characteristics, a weak interfacial bond and inherent flaws in glass particles [13], while when glass powder content = 0.7wt. % with different percentage of added foam agent, it is observed that the compressive strength was increased with decreasing foam agent and glass powder, the recorded value (10.26 MPa), (6.54 MPa) at 28 days for both curing. Compressive strength of foamed concrete contained gloves rubber waste (GV) is given in figure 8 a, b. The results show effect of adding the rubber waste on the compressive strength values. After adding the gloves rubber with ratios 1 and 5wt. % the compressive strength was increased to (8.48 MPa) of water curing and (6.86 MPa) of air curing with adding 1wt. %GV while slight decreasing in compressive strength to (6.14 MPa) in water curing and (5.20 MPa) in air curing at 28 days after adding 5wt. %, but compressive was decreased when 3wt. % GV was added.
Figure 7. Compressive strength of foamed concrete contained 1%, 0.8% of foam agent (FA) and different percentages of glass powder (GP) cured in (a) water (b) air for 7, 14, 28 days.

Figure 8. Compressive strength of foamed concrete contained 0.8% of foam agent (FA) and different percentages of gloves rubber waste (GV) cured in (a) water, (b) air for 7, 14, 28 days.

5.3 Flexural Strength
Flexural strength of foam concrete is increasing with increased curing age as given in figure 9 a, b. The results show that the optimum flexural strength value increases to (3.79 MPa), (3.87 MPa) of water and air curing respectively of foam concrete that contains 0.8 wt. % foam agent and 0.7 wt. % (GP) but it decreases when increasing the content of foam agent and glass powder.

Flexural strength of foam concrete reinforced with gloves rubber (1, 3, 5 wt. %) and with two curing method at seven, 14, 28 days, is given in Figure 10 a, b. The results show that the flexural strength was increased to (4.14 MPa) of water curing and (3.56 MPa) of air curing for the samples reinforced with 1 wt. % (GV), but it equals (3.52 MPa) at water curing and (3.15 MPa) at air curing of sample contained 5 wt. % (GV), at age time 28 days. It is observed that the flexural strength was increased with increasing gloves rubber to 1 and 5 wt. % of both curing methods. However, flexural strength value was decreased after adding 3 wt. % of gloves rubber waste.
Figure 9. Flexural strength of foamed concrete contained 1%, 0.8% of foam agent (FA) and different percentages of glass powder (GP) and cured in (a) water (b) air for 7, 14, 28 days.

Figure 10. Flexural strength of foamed concrete contained 0.8% of foam agent (FA) and different percentages of gloves rubber waste (GV) cured in (a) water, (b) air for 7, 14, 28 days.

5.4 Splitting Tensile Strength
Splitting tensile strength of foam concrete reinforced with 1% and 0.7wt. % of glass powder are given in Figure 11 a, b. It results show that the sample contained 1wt.% of glass powder (GP) with 1wt.% foam agent (FA) has splitting tensile strength equal to (1.31 MPa), (0.85 MPa) of each curing method. These values were increased to (1.62 MPa) in air curing and then water curing with adding 0.7 wt.% glass powder. The sample contained 0.8wt.% foam agent with same percentage of (GP) records (1.71 MPa), (1.52 MPa) of water and air curing. It is clear that the splitting tensile strength decreases with increasing the glass powder content, these results agree with that of the researcher (K. Rubini) [14].

Splitting tensile strength of foam concrete toughened with gloves rubber (1, 3, 5wt. %) for the two-curing method at 7, 14, 28 days, are given in Figure 12 a, b. The results illustrate the optimum splitting tensile strength values (1.58 MPa), (1.29 MPa) at water and air curing with different curing times, after adding 1wt.% of (GV). The values of splitting tensile strength were decreased with increasing gloves rubber, although decreased strength but this samples show a cohesive behavior of foam concrete (FC) at failure. All these results corresponded with the results of R. Devaki [15].
Figure 11. Splitting tensile strength of foamed concrete contained 1%, 0.8% of foam agent (FA) and different percentages of glass powder (GP) cured in (a) water (b) air for 7, 14, 28 days.

Figure 12. Splitting tensile strength of foamed concrete contained 0.8% of foam agent (FA) and different percentages of gloves rubber waste (GV) cured in (a) water, (b) air for 7, 14, 28 days.

5.5 Thermal Conductivity
Thermal conductivity values of foam concrete contained 1 and 0.7 wt.% glass powder (GP) are shown in figure 13. The results show that the thermal conductivity is gradually decreased with increasing glass powder and foam agent, the optimum thermal conductivity reached to (0.4096 W/m·°C) contained 1wt. %FA and 1wt. % GP. This is attributed to the lower density and morphology of glass powder particles, therefore the replacement of cement ratio with glass powder lead to reduce the transfer of heat through foamed concrete, while the thermal conductivity increases with decreasing the glass powder content. It seen in the same Figure, thermal conductivity reduced to value (0.8661 W/m·°C) after adding 1wt.% gloves rubber waste with 0.8wt.% (FA), while thermal conductivity increases with increasing gloves rubber waste.

Figure 13. Thermal conductivity of foamed concrete contained 1%, 0.8% of foam agent (FA) and different percentages of glass powder (GP) and gloves rubber waste (GV).
6. Conclusions
The prepared sustainable foamed concrete by using recycled materials such as glass powder (windows glass) and rubber wastes (gloves) used after treatment to produce the foamed concrete as a substitute filler for cement. This foamed concrete is distinguished with lower density and a suitable strength. As a result of the experimental works about the produced foamed concrete, some conclusions can be extracted from this study inclusive:
1 - The addition of glass powder and rubber wastes (gloves) effects on the mechanical and some physical properties such as the compressive strength, flexural strength (F.S), splitting tensile strength (T.S) and thermal conductivity.
2 - All these characteristics have increased with increasing the density values and decreased glass powder to 0.7wt. %, 1wt. % rubber waste (gloves) and foam agent content to 0.8wt. %.
3 - The best thermal conductivity value was achieved for the samples contained 1wt. % of each FA and GP and 0.8wt. %FA+1wt. %GV.

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