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Use of glass waste on the properties of concrete

Gurbanova Rena Vagif[1], Khabibova Almas Qudrat[1], Atamaliyev Elsever Faiq[2]
[1] Associate Professor, Department of Chemistry and Inorganic Substances, Faculty of Chemical Technology, Azerbaijan State University of Oil and Industry, Baku, Azerbaijan
[2] Department of Chemistry and Inorganic Substances, Specialty Solid Waste Processing Technology, Faculty of Chemical Technology, Azerbaijan State University of Oil and Industry, Baku, Azerbaijan

Abstract
One of the main tasks of geoecology is the preservation of life-supporting resources of geosphere shells under the influence of anthropogenic factors, their protection and rational use. Currently, one of the promising areas for reducing negative technogenic impacts on the environment and the population during construction and economic activities is the creation of environmentally friendly energy-resource-saving technologies, in which secondary raw materials are used instead of primary ones, which allows reducing the volume of disposal of non-recyclable waste in the environment and involving them into the resource cycle, while reducing the volume of use of primary natural resources. Glass waste, the bulk of which is cullet, is one of the main components of municipal solid waste (MSW), some types of industrial waste and electronics. Non-recyclable waste glass, placed in the environment without the necessary protective measures, causes contamination of soils, surface and groundwater with leaching products, takes land out of economic circulation as a result of contamination with traumatic glass fragments, which leads to restrictions on the use of natural resources, excessive wear of machines and mechanisms as a result damage to their moving parts and elements. Cullet is reused to a small extent, and the most environmentally hazardous lead-containing glass is not recycled at all and is not traditionally separated from the general flow of cullet, which makes it difficult to involve the material potential of glass waste in the resource cycle. Considering the environmental hazard of non-recyclable glass waste, their recycling to produce environmentally friendly building materials using low-waste technology is an urgent task. This article is devoted to research to justify the possibility of using cullet as an aggregate for the production of concrete, to study the properties of the resulting concrete using cullet, to clarify the mechanism of influence of cullet on the properties of concrete. Concrete containing powdered glass has demonstrated excellent durability properties due to its finer porous structure and compacted microstructure. The results showed that waste glass has the potential to be used as coarse and fine aggregates in concrete production and provided best practice recommendations for further research.

Keywords: Ultra-high performance concrete, glass powder, sustainability, mechanical characteristics, microstructure, recycling, glass waste, recycling, concrete characteristics, waste disposal

Introduction

An urgent task of the construction industry at present is the production of effective materials for construction purposes, characterized by high physical and mechanical properties, durability, operational and aesthetic indicators, and low cost. At the same time, special attention is paid to the issues of rational use of raw materials and energy resources, introduction of low-waste technologies, and reduction of the uncontrolled impact of human activities on the environment. The solution to this problem is the development of technologies for producing building materials based on the use of solid waste, including household waste (MSW). In this work, special attention is paid to the use of cullet glass (CG) as a type of solid waste. Cullet is a hard-to-dispose waste that is not exposed to water, atmospheric phenomena (precipitation, solar radiation, temperature changes) and does not degrade under the influence of organic, mineral and biologically active organisms. The share of CG in solid household waste from large cities in our country is 8-18%, which is 2.4-2.9 million tons [1, 2]. If the amount of solid household waste per year in Russia is taken to be 400-700 kg per person, then 60-100 thousand tons of cullet per year are generated per million people. The environmental impact of such quantities of CG is not clear. It is known that SB arriving at landfills has a different dispersed composition, and glass in a dispersed state undergoes activation with the formation of a chemically active phase (hydrated silicon oxide) on the surface [3–5]. It is known that the permissible value of glass leaching with water in terms of mg Na_2O per 1 dm^2 is in the range of 0.71–0.76 [3]. If we take the average glass thickness to be 2.7-3.3 mm, then the average leaching value should be taken at the level of 0.74 mg. Then a ton of cullet with an average density of 1300 kg/m^3 will release 10.7 g of Na_20 or 13.8 g of pure alkali NaOH when leached with water. Consequently, per year, from 60–100 thousand tons of cullet per million inhabitants, 828–1380 kg of pure alkali will be released, which leads to degradation of the soil resource. At the same time,CG, which is part of solid waste, is a mixture of glass of various chemical and fractional compositions, which has a wide range of technical and technological characteristics: chemical resistance, hardness, strength, wide viscosity range and is a valuable mineral resource. The use of CG as a secondary raw material allows you to reduce the consumption of scarce and expensive raw materials (soda ash, sand). Thus, recycling 1 million bottles saves 300 tons of quartz sand and 100 tons of soda ash, and the use of CG as a secondary raw material allows saving on primary raw materials for every 100 kg of cullet introduced [6-9]. An increase in CG in the charge for every 10% leads to fuel savings by 4.4% and electricity by 1.1%.

The most common method of recycling cullet is concrete manufacturing technology [10–12]. The work aimed at using CG is based on the theoretical proposition that glass in a finely dispersed state at elevated temperatures in an alkaline environment has astringent properties and is capable of forming a durable building material as a result of monolithic solid phase. After sorting, crushing, grinding and scattering into fractions, glass can be considered fully prepared for the production of building materials. When cullet is introduced into concrete as a filler, it causes the interaction of amorphous silica, which is part of the glass, with cement alkalis. It is known that the structure of concrete is a capillary-porous system consisting of filler, binder and capillaries filled with air, water and water vapor. When mixing Portland cement with water, the alkali oxides Na_20 and K_20 contained in it are dissolved. As a result, the solution located in the voids of concrete becomes highly alkaline. In addition, some concrete fillers containing amorphous silica tend to react with this solution. As a result of this reaction, a gel-like substance is formed from alkali metal silicates. In turn, the gel, enclosed in a cement stone and capable of swelling, causes internal pressure, which leads to the occurrence of cracks and, as a consequence, to the destruction of the material. Thus, the use of cullet as a filler in concrete is promising in solving the problem of minimizing alkali-silicate interaction (ASR). In works [12–14], the conditions for the development of alkaloids in concrete were analyzed and it was found that the result of the interaction of the cement material with the cullet filler is influenced by: - the degree of glass dispersion; - use of amorphous silica as an active dispersed hydraulic additive; - chemical modification of glass, which consists in removing Na^+ ions from the surface in the process of ion-exchange modification of the surface. The authors [12–13] experimentally established that the size of destruction and, as a consequence, a decrease in the strength of the cement matrix, depends on the degree of dispersion of the introduced cullet. Thus, in [13] it was shown that glass with a particle size of 1-4 mm, when introduced into a concrete matrix, causes the expansion of samples by more than 0.2%, which is 5 times higher than the permissible values. It was established in [12] that it is advisable to use cullet of the 1.25-5 mm fraction in concrete as fillers. In this case, the strength of concrete composites will significantly exceed the strength of concrete, for example, with sand aggregate. An increase in the strength of concrete can be achieved by surface crystallization of coarse aggregate (fraction size more than 1 mm) at a temperature of 700–720°C, in the presence of crystallization centers, such as quartz glass powder. In this case, the expansion of the samples, leading to loss of strength, decreases by 2–7 times compared to samples obtained on unmodified aggregate. As for the use of fine glass (with a particle size of 1–4 mm), it is advisable to use it as a binder or process it into granulated foam glass. According to [13, 15], the expansion of concrete samples with filler of this size is 0.02-0.04%. According to the authors, this is due to the fact that silicate glass, when interacting with water, undergoes hydrolysis with the release of sodium ions into the aqueous phase. In this case, a film of hydrated silicon oxide forms on the surface and the formation of new substances on the surface if the necessary compounds are present in the solution. This means that in the case of using highly dispersed glass, the material acquires a more developed surface and the possibility of targeted use of such interaction increases many times over [13, 15]. Reducing the alkali-silicate interaction in concrete by introducing additives of amorphous highly dispersed silicon oxide in an amount of 0.5 to 5 wt. %: reviewed in [13, 15]. The additives used were: silica gel (particle size 60 microns), aerosil and glass, ionically modified by replacing Na^+ with H^+. It was found that these additives effectively suppress the alkali-silicate interaction and make it possible to obtain concrete that meets the standard. The amount of cullet used in mixtures from different countries and manufacturers depends on the purpose of the concrete.

Esmaili and Al-Mwanes [16] investigated ultra-high performance glass concrete (UHPGC) made from glass powder as a partial replacement for cement at different replacement levels [17, 18]. They showed that the produced UHPGC has high mechanical properties such as compressive, tensile and flexural strength [19-21]. In addition, glass powder GP reduces the likelihood of chloride corrosion of steel and reduces the penetration of chloride ions into concrete. Zhang *et al* [22]. used nano-SiO_2 (NS) particles to produce high-performance concrete (HPC). The results show that the addition of Nano SiO_2 significantly improves the durability and mechanical properties of HPC. Therefore, this paper aims to investigate the properties of recycled waste glass (RWG) as an aggregate and to study the chemical composition and physical properties of RWG. This study also aims to investigate the properties of fresh and seasoned conventional HPC. Moreover, the study aims to highlight several important properties such as workability, density, compressive strength, flexural strength, splitting strength as well as the relationship between the properties which is shown in various tables and figures.

Scientists have been talking about the possibility of recycling glass waste through the building materials industry since the 70s, but practical research in this area has not been carried out. Currently, a number of domestic and foreign universities are engaged in the development of building composites using it. For example, specialists from the Faculty of Engineering and Applied Sciences at Columbia University (New York) are working on the problem of replacing stone aggregate in concrete with broken glass. Domestic scientists are also working on solving similar problems [23]. The main objective of our research was to develop effective technologies that make it possible to use broken glass not only as a filler, but also as the main component of the binder. Similar work was and is being carried out by professors A.P. Merkin, Yu.P. Gorlov and their students. They developed compositions of cementless binders based on natural and artificial glasses, capable of curing under hydrothermal treatment conditions [24-27]. Taking into account the high energy intensity, and, accordingly, the cost of such technological operations, the most promising way of recycling broken glass through the building materials industry seems to be the production of a binder and concrete based on it, hardening at an isothermal cycle temperature not exceeding 90°C. This paper presents the results [28] of a study of such composites. In order to target the experimental research, at the first stage, research was carried out in the field of hardening of binder systems. The theoretical prerequisites for the creation of binders were that broken glass in chemical composition is close to sedimentary and metamorphic rocks such as natrolite, mordenite, etc., the formation of which in nature occurs as a result of low-temperature hydrothermal reactions. Numerous researchers have found that such compounds can be synthesized by mixing natural or artificial glasses with aqueous solutions of alkalis. The hardening of these systems is based on the reaction between silica and aqueous solutions of alkali metal compounds. However, this process occurs at elevated temperatures and pressures. We have found that the formation of compounds similar to those mentioned above can be carried out without the use of autoclave treatment. This is achieved if corrective additives are additionally included in the system. It was found that local clays, as well as production waste from construction industry factories specializing in the production of ceramic materials and products (powdered fractions of expanded clay, ceramic bricks, etc.) are suitable as such additives. The hardening mechanism of the binder based on broken glass is presented as follows. Initially, under the influence of alkali and elevated temperature, finely dispersed amorphous silica dissolves from the surface of glass particles, as a result of which its concentration in the solution increases, steam condenses, which leads to a decrease in the pH of the environment and causes a polycondensation reaction with the formation of a polysilicic acid gel, which glues together incompletely dissolved particles glass and aggregate grains. Further exposure to temperature during thermal and humidity treatment leads to crystallization of the acid gel with the formation of sparingly soluble hydroalumino silicate compounds.

In general, waste glass can be completely and substantially reused and recycled while maintaining its physical properties and chemical composition [29–31]. However, the mixed color of broken wastes glass (WG) makes the recycling procedure infeasible and extremely costly as these materials may cause deviation in their chemical composition [32]. Contaminants and impurities that may enter the WG in combination with the mixed color can affect the chemical composition of the new glass produced [32, 33]. The level of reuse and recycling of WG is very low worldwide, and it is mainly concentrated in the areas of packaging and packaging [33]. In the United States alone, 11.5 million tons of WG were produced by 2010, with a recycling rate of 27% [34]. However, in 2008, the total WG in European countries was expected to be 4.1 million tons, which is about 60% as a recycling rate [35]. In Sweden, approximately 44,000 tons of mixed colors and 195,000 tons of isolated colored WG were produced in 2010, with a recycling rate of 93% for isolated colored WG [36]. Thus, glass waste management can be considered as one of the major challenges faced by researchers and scientists around the world due to the lack of open sites and landfills, low recycling rates and lack of sufficient open space areas [37, 39].

Using cullet as concrete filler

Increasing production volumes of concrete and reinforced concrete is impossible without increasing the amount of aggregates. With an average annual production volume of concrete and reinforced concrete of more than 60 million m^3 (including more than 20 million m^3 of prefabricated and more than 40 million m^3 of commercial) and mortars of 20–25 million m^3, the need for non-metallic aggregate is more than 50 million m^3 (or more than 65 million t), in fine aggregate 50–55 million m^3 (or more than 70 million tons). However, expanding the extraction of the main types of concrete aggregates cannot always be realized. Deposits of non-metallic materials such as building stone, sand and gravel mixtures and building sands cannot always be used, since they are built up, located in floodplain river terraces or in other protected areas [40]. At the same time, household and industrial cullet, which is not currently sold, but has high strength characteristics and availability, is practically not used as a concrete filler. In our country, about 35–40 million tons of solid household waste are generated annually, while only 3–4% of solid waste is recycled [41, 42]. The amount of cullet for different areas is 6–17 wt. %. The annual volume of cullet ending up in municipal solid waste landfills is 2–6 million tons. Compared to the annual demand for fillers, this value is small, but it is necessary to take into account the environmental effect not only from the disposal of the solid waste component, but also the possibility of reducing the extraction of natural resources when replacing on raw materials of anthropogenic origin. In addition, the use of waste is 2–3 times cheaper than natural raw materials [43], fuel consumption when using certain types of waste is reduced by 10–40%, and specific capital investments by 30–50%.

However, the problem of interaction of soda-lime silicate glass with cement stone creates serious problems when using cullet as an effective filler in cement composite materials. The same can be said about many glass-containing materials - mineral and glass fibrous materials (wool), fiberglass, foam glass, which could be used as effective fillers in cement compositions.

As a result of the alkali-silicate reaction, a gel is formed, which swells in the presence of moisture, leading to the formation of cracks and destruction of concrete. This reaction can also occur in ordinary concrete if the filler of natural origin contains reactive (usually amorphous) silicon oxide. On the one hand, the glass filler promotes the occurrence of an alkali-silicate reaction in concrete due to the fact that glass contains Na^+ on the surface, which is capable of creating a certain concentration of NaOH in the cement composition even in the absence of alkali in the original cement, and on the other hand, it is glass that contains compounds on the surface silicon oxide in amorphous form. There are known studies of soda-lime glass as a filler for cement paste. In this case, cullet of various compositions and dispersion was added to the cement composition, and the expansion and strength of the resulting concrete were mainly studied. Thus, research was carried out at Columbia University (USA) by Professor S. Meyer [44]. It has been revealed that the addition of glass to the composition in most cases leads to the process of alkali-silicate interaction and a decrease in strength. Studies have also been carried out on the influence of temperature and glass composition on the process [45]. It was found that highly dispersed glass powders lead to a lack of expansion of samples [46]. The authors make an assumption about the high speed of the alkali-silicate reaction process in this case, which leads to the completion of the process in 24–28 hours, as a result of which expansion and destruction of the samples cannot be recorded in the future. It can be assumed that as possible ways to suppress the process of alkali-silicate interaction in glass-cement compositions, the authors propose the use of glass of a certain granulometric composition [47, 48], the addition of highly dispersed glass [49], and the modification of the composition by adding lithium or zirconium compounds.

Research [50] showed that it is impossible to avoid the alkali-silicate reaction when using cullet as a fine aggregate without additional treatments and additives. Article [51] considers the problem of internal corrosion associated with the occurrence of an alkali-silicate reaction between filler particles. The authors of the article [51] propose the following solutions to the problem: 1) the use of low-alkaline cement binders; 2) the use of fillers that do not contain reactive silicon dioxide. In addition, it is proposed to use a minimum amount of cement or make concrete using cements containing a small amount of alkalis, use cement additives that reduce the amount of alkalis in cement, or introduce water-repellent and gas-releasing additives. The use of a standard range of concrete modifiers can significantly slow down the manifestation of alkali corrosion. The authors of the article [52] came to this conclusion. They suggest using Lignopan B-4, UPD-1, ML-2 and (especially effectively) superplasticizer S-3 as a suppressor of expansion deformations during alkaline corrosion. In article [53], the authors used an active mineral additive of an acidic nature, which led to a decrease in the basicity of the binder and a decrease in alkali activity due to the chemical absorption of the latter by the active components of the mixed binder. The hydraulically active components of the mixed binder are amorphous silica of zeolite-containing rock and the glass phase of thermal power plant ash. An alternative to additives was the methods described in articles [50, 54]. The authors came to the conclusion that crystallization of glass on the surface of the filler is necessary, which will lead to the suppression of the silicate-alkali reaction. To do this, it is necessary to heat treat the glass in a furnace, after which a crystalline "film" is formed on the surface of the glass, which will subsequently prevent the onset of corrosion. The authors of the article [54] also considered the complete suppression of the alkali-silicate reaction by adding highly dispersed silica oxide (0.5–5%) and used ion-modified glass with the replacement of Na^+ by H^+. To effectively use glass aggregate, it is necessary to determine the fractional composition. In article [50], various fractional compositions of cullet in concrete were considered and their effect on the final strength was analyzed. As a result, it turned out that the preferred fraction is 1.2 mm and above. The very minimum strength is achieved in a fraction of 0.1–0.3 mm. Significant expansion of the samples (due to the silicate-alkali reaction) is achieved on a 1.25 mm aggregate. When the particle size is less than 50 microns, an anomalous increase in strength occurs, which is due to the high specific surface area. To use large fractions from 5 to 20 mm, two additives are needed: a superplasticizer and a retarder. This will reduce the impact of the alkali silicate reaction on concrete [56]. The authors of article [55] obtained data which describe the use of various types of cullet in concrete depending on the purpose of the structure. Thus, for autoclaved products, the addition of cullet in a volume of 1.2% makes it possible to obtain a material with a density of 1,230 kg/m^3. Ground glass in a composition of 2–30% with various additives makes it possible to produce acid-resistant cellular concrete. Finely ground cullet in an amount of 2–5% is used to produce heat-resistant concrete. According to the results of work [56], it was revealed that the use of cullet in an amount of 30% of the total aggregate is the most effective, and the minimum effective amount was about 10%. Thus, an analysis of literary sources shows that the use of glass waste as fillers for concrete, on the one hand, is economically profitable and expedient, saves natural resources and energy for their processing, and on the other hand, it is effective for obtaining new types of concrete and their modifications, satisfying all modern requirements with their characteristics. The optimal use of waste glass is to use it as an aggregate for concrete. The most effective application is coarse aggregate or raw material for processing into foam glass. These options do not require additional measures against silicate corrosion. However, you can use cullet as fine, medium and coarse filler, but with the use of special additives that prevent the occurrence of alkali-silicate corrosion, or subject the filler to heat treatment. The use of cullet as a concrete aggregate is a promising, cost-effective and resource-efficient method for obtaining the required technical characteristics of concrete that me*et al*l standards. medium and coarse aggregate, but with the use of special additives that prevent the occurrence of alkali-silicate corrosion, or subject the aggregate to heat treatment. The use of cullet as a concrete aggregate is a promising, cost-effective and resource-efficient method for obtaining the required technical characteristics of concrete that me*et al*l standards. medium and coarse aggregate, but with the use of special additives that prevent the occurrence of alkali-silicate corrosion, or subject the aggregate to heat treatment. 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Wang *et al* [57]. studied the effect of introducing glass as fine aggregates into three different mixtures to achieve strengths of 21 MPa, 28 MPa and 35 MPa at replacement levels ranging from 0% to 80%. The results showed that the compressive strength decreased significantly at replacement levels of more than 20%. Particle size of waste glass used as fine aggregate by Tuaum *et al* [58]. was somehow less than the fine aggregate as in Figure 1. Abdalla and Fan [59] studied the properties of concrete containing finer crushed glass used as fine aggregate in the best ratio to achieve maximum compressive strength of concrete blocks as well as influence of glass aggregates (GA) substitution level on the expansion rate of the alkali-silica reaction (ASR). Borhan *et al* [60]. studied the properties of glass aggregates (GA) for the production of concrete reinforced with chopped basalt fiber. The fine aggregate was replaced with recycled mixed colored glass at varying replacement levels (20%, 40% and 60% by weight) with varying fiber replacement levels (0%, 0.1%, 0.3% and 0.5%). The results showed that there was a slight decrease in compressive and tensile strength due to an increase in GA by more than 20%.

Sikora *et al* [61] concluded that waste glass (WG) can be replaced with conventional fine aggregate in cement concrete without compromising the performance of the specimens. In addition, the use of WG as a fine aggregate led to a significant decrease in thermal conductivity and a decrease in the sorption capacity of cement mortars.

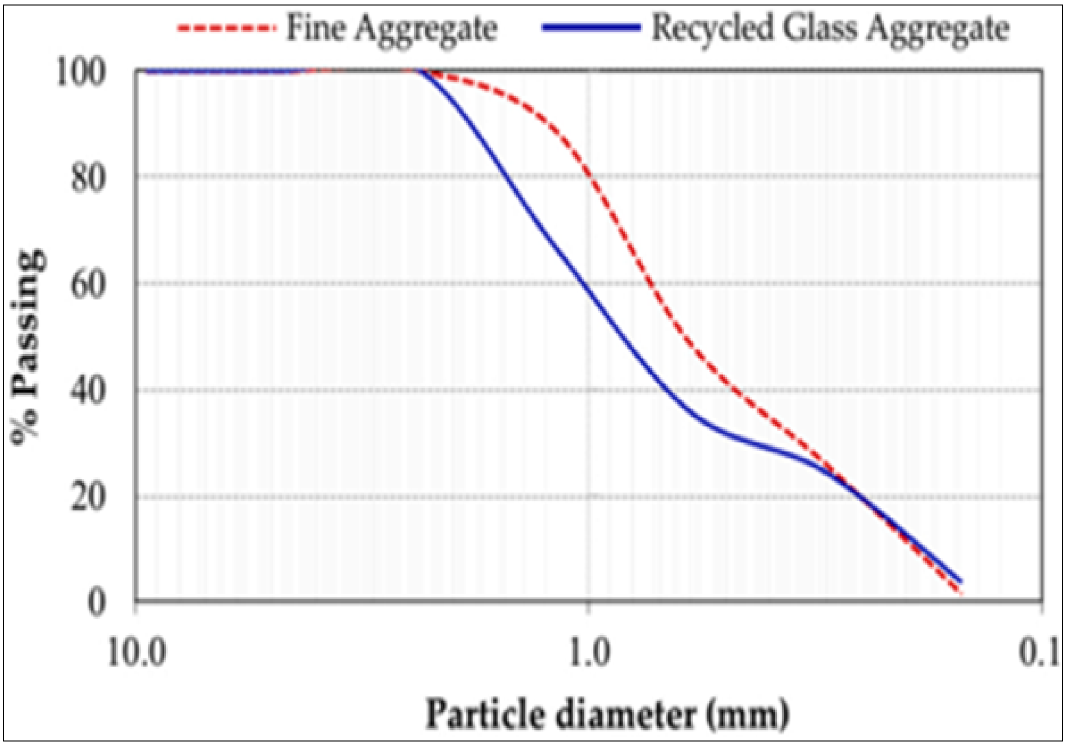

Fig 1: Particle size distribution of RGA and fine aggregate [58]

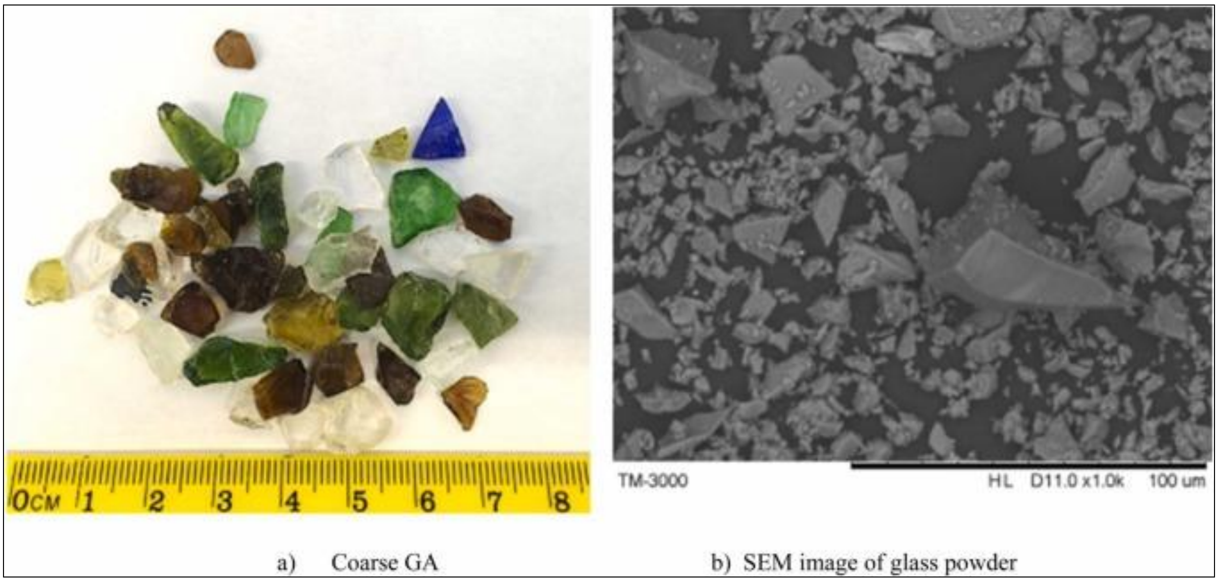

Fig 2: Glass waste [62]

The work [63] investigated the creation of cost-effective and environmentally friendly UHPC by replacing PC with glass waste (GW) of different sizes using glass work powder (GP) at replacement rates of 0%, 10%, 20%, 30%, 40%., and 50%.Glass particles (G) are substituted for fine aggregate "sand (S)" at replacement ratios of 0%, 50%, and 100%. In order to do this, eighteen mixes are prepared and experimentally analyzed after being divided into three groups. Water permeability, mechanical attributes, microstructural features, and slump flow are all under investigation. The results showed that workability was enhanced by raising the S replacement ratio with G. In addition, 20% and 0%, respectively, were the optimal replacement ratios to achieve high mechanical properties when substituting portland cement (PC) with GP and S with G. Water permeability values were significantly reduced when GP replacement rate was increased at a fixed ratio of G to S in place of PC replacement rate. Lastly, a microstructural examination validates the results of the experiment. Additionally, when compared to PC100-S50 G50 and PC100-G100, PC100-S100 was the best combination. Figure 3 shows the various phases involved in grinding glass waste.

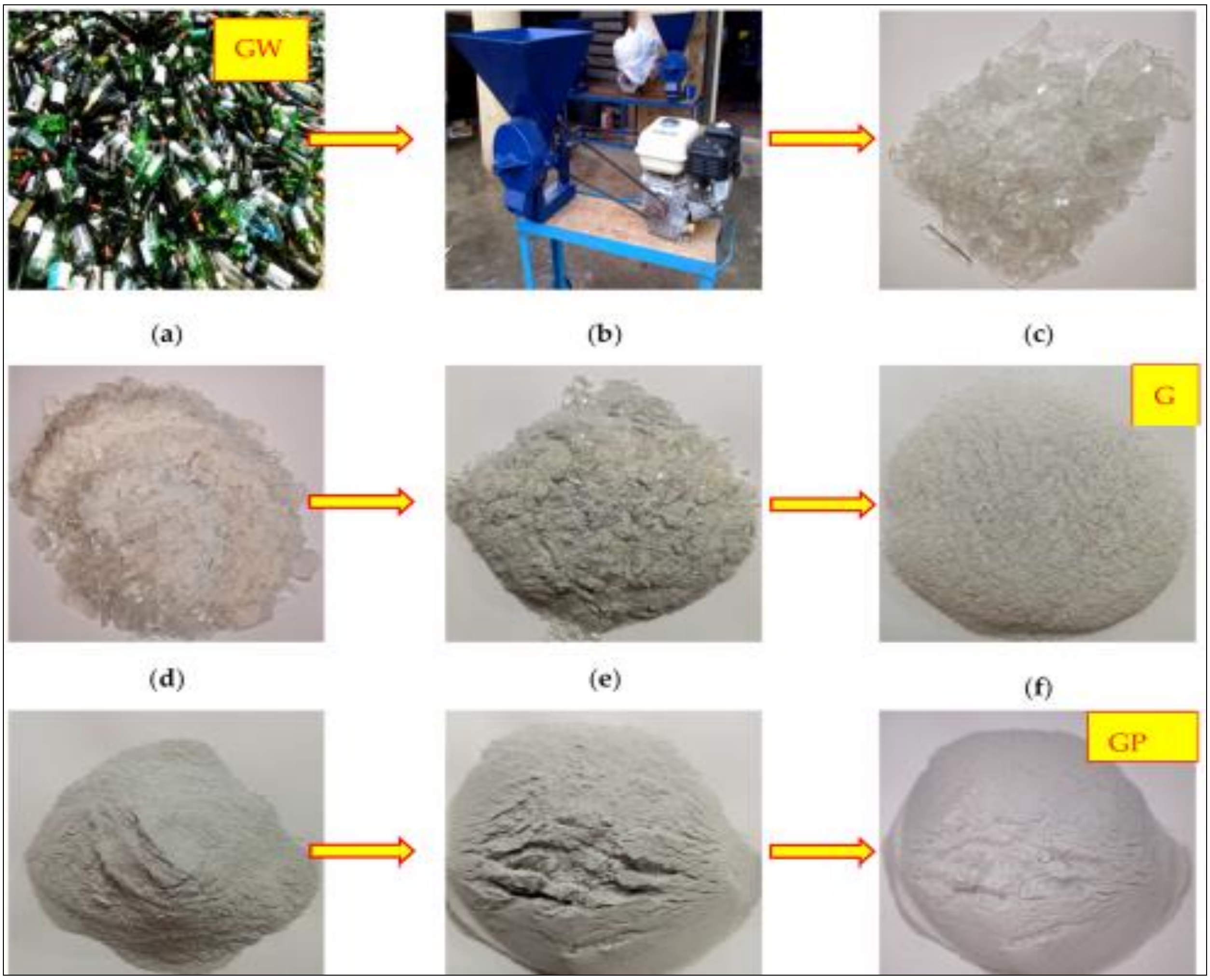

Fig 3: Different stages for glass waste milling. (a) Glass waste (GW); (b) ground mill; (c) crushed glass (size >> 4.75 mm); (d) crushed glass (size >> 4.75 mm); (e) crushed glass (size > 4.75 mm); (f) glass particles (G) used as fine aggregate (size < 4.75 mm); (g) milled Glass (size << 4.75 mm); (h) milled glass (size <<< 4.75 mm); and (i) glass powder (GP) used as a substitute for PC (size < 75 µm).

Properties of concrete containing GW

Every year, millions of tons of glass waste create terrible environmental problems around the world. Glass is mainly composed of silica. Its use in concrete can be a beneficial solution for environmental as well as economic problems. This mini-review explored various possibilities for adding value to waste glass by replacing aggregates and cement in concrete. Its effect on physicochemical and mechanical characteristics has been studied in major studies in this direction. The use of waste glass in concrete can improve the performance of concrete and be an advantage for participating in sustainable development by reducing this waste.

Many scientific studies have been conducted to use waste glass as a partial replacement for fine and coarse aggregates in concrete. Ismail and AlHashmi [64] investigated the use of waste glass as a partial replacement of fine aggregate in concrete at percentages of 5%, 10% and 20%. The results showed that partial replacement of fine aggregate with glass powders reduced ASR expansion, and fine glass waste reduced expansion compared to the control mixture. This decrease is due to the decrease in available alkali due to the consumption of lime for the reaction with glass waste and the expected decrease in the alkalinity of the system. In their work to determine the percentage of replacement of fine aggregates with waste glass to achieve the optimum value of compressive strength, Kumar and Nagar [65] found that the optimal percentage was 25% at which the compressive strength of concrete increases. for a period of 28 days up to 11.56%.

Liaquat *et al* [66]. conducted experiments to study the mechanical strength of concrete made using waste glass as coarse aggregate with particle sizes ranging from 4.75 to 12.5 mm and percentages of 10, 20, 30 and 40% by weight. They concluded that the ideal replacement rate for glass waste is 10%. On the other hand, Nwofor and Ukpaka [67] studied the replacement of fine and coarse aggregates with waste glass at percentages of 20%, 40%, 60% and 80%. They found that the optimal replacement in both cases (fine and coarse) was 20% compared to the other percentages. In contrast, Rajitha *et al* [68] found that the optimal replacement of fine and coarse aggregate was 5%.

The test results of [8] showed that the greatest result in terms of compressive strength and at 7 and 28 days of hardening was shown by concrete samples using cullet with a grain size from 0.315 to 0.63 mm, the lowest result was with a cullet grain size of less than 0. 16 mm. Consequently, it is possible to use glass cullet of large fractions, preferably above 1.25 cm, as a filler in concrete, and the strength of these concretes is comparable to the strength of conventional concrete made from natural and crushed sand. Comparing the test results, we can say that the strength of conventional concrete using natural and crushed sand exceeds the strength of concrete using cullet with a particle size of 0.315 - 0.63 mm. When the particle size of cullet with a grain size of less than 0.315 mm occurs, a sharp decrease in the strength of concrete occurs. This decrease in strength can be explained by the high specific surface area of the aggregate grains, which leads to a sharp decrease in the adhesion of glass grains to cement stone.

To obtain modified concrete using recycled glass waste, according to [69-71], nine samples (concrete cubes) were tested on the 28th day. Of these, 3 samples were without glass (control), three samples contained 10% glass, and three samples contained 15% glass. Concreting technology, as well as processing of samples in accordance with the requirements of the standard. Cement, sand, crushed stone and glass are mixed. Then the finished mixtures are poured into 10x10x10 cm cubic molds and placed on a vibrating table for one minute to compact the mixtures. After compaction on a vibration table, the samples are numbered and left for further hardening (28 days). The cement used was Portland Cement M 400, crushed stone with a diameter of 5–20 mm, a sand and gravel mixture with a particle size of up to 20 mm, and finely ground glass. The samples were tested on a laboratory hydraulic press PSU-125. In the course of the work, the following results of testing concrete cubes were obtained (Figure 4).

When replacing 10% cement with fine glass, three out of three samples exceeded the strength of the control samples. The average strength of the samples is 171.9 kg/cm^2. The strength of concrete when replacing 15% of cement with finely ground glass was much higher than that of control samples. The average strength of the samples is 224.83 kg/cm^2. That is, replacing 15% of cement with fine glass increases the strength of concrete by 10%. From the studies conducted, we can conclude that the use of fine glass to replace part of the cement is an acceptable way to both reduce the use of cement and improve the strength properties of the concrete mixture, which reduces the cost [72].

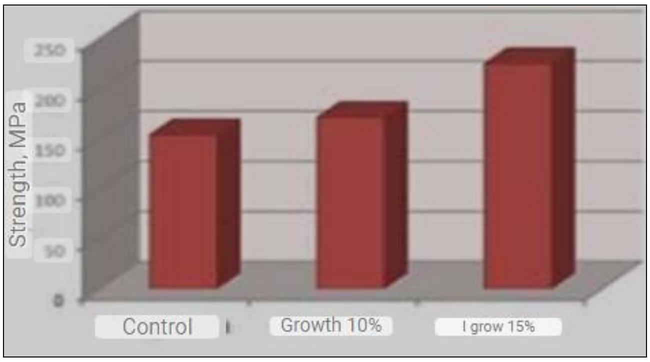

Fig 4: Strength of samples when tested on the 28th day

The workability of concrete is the property of a concrete mixture to be uniformly distributed in a thin layer. For the strength of the masonry, it is necessary that the concrete pouring is in contact with the structural elements in each of its irregularities, and the mortar must not have unfilled spaces inside itself. Workability depends on the internal forces of the concrete and determines the ability of the mortar to fill the required shape when placed.

The workability of a concrete mixture is determined by the mobility and rigidity of the mortar, as well as the ability to retain moisture within itself. If workability is low, then the concrete mixture will have low resistance to adverse weather conditions.

The workability of a rigid mixture can be increased by adding water and certain additives that increase the air content and plasticity of concrete. Also, an important factor for increased workability is the composition of the aggregates and the grain size of the cement composition.Wet concrete is easier to lay than dry concrete and is more fluid and mobile.

There are many tests to measure this property of concrete based on different principles such as slump and flow tests. The authors concluded that the workability of concrete decreases with increasing replacement of cement with glass powder. This is due to the increase in surface area of the glass powder as well as the angular shape of the glass particles. Additionally, Han *et al* [73]. found that the amount of slump decreases with the addition of glass powder, so large amounts of water are required to obtain the same workability as the control mixture. Aliabdo *et al* [74]. showed that the use of glass powder as a cement additive reduces concrete slump. This trend can be explained by an increase in the content of fine-grained materials, which increases the cohesiveness of the concrete mixture.

Conclusion

Currently, construction practice is characterized by the expanding use of high-tech concretes of a new generation, which include dense, high-strength modified concretes. Given the high cost of natural raw materials, research work that identifies new opportunities for using waste in the creation of building materials based on them is of particular value. Increasing attention is being paid to the issues of recycling industrial and household waste. This is facilitated by the deteriorating environmental situation, especially in large cities. The development of directions for the use of technogenic raw materials and municipal waste in the production of high-strength modified concrete is promising and innovative.

Thus, the article discusses various ways of using waste glass in concrete by using aggregates instead of glass, which reduces the amount of waste in nature and reduces the cost of concrete. This study differs from other uses of waste glass in concrete because it examines the effect of replacement rate and particle size of this waste on improving the properties of fresh and hardened concrete.

Previous studies have mainly studied concretes using soda-lime glass. Little research has been conducted regarding the effects of other types of WG as an aggregate or cement replacement in the concrete production process. The incorporation of WG into concrete and cement paste has great potential for structural and non-structural applications despite inconclusive results.

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