Use of waste glass in concrete: A review

Oksana Berdnyk [1], *Serhii Vyhovskyi* [2]

[1] Kyiv National University of Construction and Architecture,
Kyiv, Ukraine 03037,
[1] kseniareznik87@gmail.com, orcid.org/0000-0001-5321-3518,
[2] Institute for Binders and Materials,
[2] production.dep@grandbeton.com.ua, orcid.org/0009-0003-5898-1200

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Abstract. Concrete is widely used construction material in the present industry. The concrete consists of cement, fine aggregates and coarse aggregates. Concrete is strong in compression and weak in tension. Also, the cement manufacturing industry on an average emits 7% of greenhouse gases to earth's atmosphere which leads to global warming. In order to address these environmental affects extensive research is ongoing into the use of cement replacements, using many waste materials (like waste glass, plastics, fly ash, etc.) and industry's by-products. Waste glass is a non- biodegradable material and disposal of waste glass into the land results in the soil pollution. So, to avoid these disposable problems waste glass may be used as partial replacements of coarse and fine aggregates. It's possible to add glass in the concrete by replacing either of the ingredients partially in a number of forms. Glass may be added in crushed form or in powder form along with the addition of admixtures/plasticizers or without addition of any of the alternate materials in the nominal concrete. Accordingly, a study about various aspects of usage of glass has been made in this paper to include it in concrete as an ingredient so that the best possible usage of glass form may be finalized and same may be used in the concrete with a partial replacement.

Keywords: waste materials, glass powder, concrete, admixtures, aggregate, cement replacement, partial replacement.

Oksana Berdnyk
Scientific Research Institute for Binders and Materials
PhD, Associate Professor

Serhii Vyhovskyi
Postgraduate Scientific Research Institute for Binders and Materials
Operations director «Grand Beton»

INTRODUCTION

Concrete is a frequently used construction material. Looking into its composition, it contains cement, sand, gravel, and water, and sometimes admixtures are added to achieve desired effects. Cement, being a binding material and a crucial element of concrete, makes up 7–15% portion of it [1]. Aggregate makes up 70%–75% of the total volume of concrete. Aggregates were used as a construction material in 48.3 billion tons worldwide in 2015 [2]. It is expected that by 2050, more than 70% of the world's countries and territories will be more than 60% urban, and the remaining 38% will be at least 80% urban. Only two continents, Africa and Asia, will be able to accommodate the world's expected population growth. By 2050, these continents will have attracted nearly 90% of the world's 2.5 billion new residents. A growing population is definitely connected to the proper construction and sustainable infrastructure [3]. The global concrete production rate is estimated to be about one ton per person per year, and that this rate is continuously rising

[4]. The cement industry contributes 5% of worldwide CO_2 emissions due to its energy-intensive nature [5]. Depending on the type of fuel used, one ton of cement is estimated to produce 0.9 to 1 ton of CO_2 . The largest environmental challenge of present time, according to scientists, is simulated climate change which has lead the path for global warming, which is the result of continuous and steady rising quantities of greenhouse gases, mainly CO_2 , in the earth's atmosphere over the past 100 years [6]. In order to reduce cement content, enhance workability, boost strength and extend the life of concrete, supplementary cementitious materials are frequently used in concrete mixes [7]. Waste Glass Powder (WGP) is potentially pozzolanic and, with proper preparation, can be used as a cement paste material. The adequate replacement level of WGP is 10% for cement in concrete [1]. Concrete with suitable properties might be made by replacing 40% of the cement with WGP. However, concrete with the substitution level of 10–20 percent shows high tolerance to chloride ion penetration, thus making it perfect for structures near the shore [4]. Glass is a useful member of the garbage family in many rural and urban areas, and it is made up of a variety of inorganic raw materials that are processed into a stable, inert, hard, homogenous, amorphous, and isotropic material [8]. The tremendous amount of WG is a concern for the world now, with countless amount of tons of glass trash produced every year around the world. Because of its non-biodegradable nature, it takes up a lot of space in landfills and poses serious environmental risks [9]. Calcium and silicon are the major constituents of the glass, and because of its pozzolanic nature in finely grounded form, it can be utilized as a cement alternative in concrete [10]. To turn the problem into a solution and to minimize the adverse effects of WG, is to utilize them in various fields. The construction industry is one of the best sites for the recycling of WG. On one hand, it is economical and environmentally friendly, and on the other hand, it relieves society of a burden. However, the introduction of WG of different types and quantities into concrete creates both drawbacks and solutions. At the beginning, the drawback was the introduction of a procedure to convert WG into useful cullet. Impact and abrasion crushers are evident in this regard to carrying out this operation. Glass is more abrasive as compared to most natural aggregates, which results in excessive wear and also high maintenance costs of the equipment. Moreover, the shortcoming of most crushers is the creation of sharp elongated glass cullets, which are at the same time both unsafe to handle and unfit to use [11]. Implosion technology was defined in mid-90s of 20th century, allowing for a revolutionary method of producing glass cullet with no sharp edges. In its apparatus, it includes a gravity chamber, a high-speed rotor that produces a harmonic resonance, and a feed system [12]. An attempt has been made in this review to present the effects of WGP used in concrete as partial replacement of cement.

PROBLEM FORMULATION AND SOLUTION ALGORITHM

Waste glass is a non-biodegradable material and disposal of waste glass into the land results in the soil pollution. So to avoid these disposable problems waste glass is used as partial replacements of coarse and fine aggregates. Use of waste glass in concrete makes the structure denser, this results in reduction of water absorption and improves durability of concrete. The addition of glass powder in concrete shows improvement in the compressive strength, flexural strength and tensile strength. It's possible to add glass in the concrete by replacing either of the ingredients partially in a number of forms. Glass may be added in crushed form or in powder form along with the addition of admixtures/plasticizers or without addition of any of the alternate materials in the nominal concrete. Accordingly the present study has been planned under following sub headings:

- Use of waste glass powder as a replacement in concrete
- Use of waste glass as partial replacement in concrete
- Use of glass powder and aggregates as partial replacement in concrete.

Use of Waste Glass Powder as a Replacement in Concrete

Vijay Kumar et al. (2013) [19] examined that worldwide concrete industry contributes around 7% of ozone depletion gases to the earth's atmosphere. So in this research finely glass powder was used as partial replacement of cement for new concrete. Glass powder was mostly replaced as 10%, 20%, 30%, 40% and tried for its compressive strength, tensile strength and flexural quality upto 60 days of curing age and results obtained were compared with those of regular cement. From the results it is discovered that glass powder can be utilized as substitute material upto molecule size less than 75 µm to avoid salt silica reaction. It was also concluded that with increase in glass powder content upto 40% it's compressive strength increases further increase in glass powder leads to decrease in its compressive strength. Vasudevan and Kanapathy Pillay et al. (2013) [18] did their research on examining the impact of utilizing the waste glass powder in concrete. The properties of the specimens were determined by the workability test, density test, and compressive strength test. For each kind of concrete, six samples of 150mm x 150mm x 150mm cubes were casted. The each sample were tried at the ages of 7, 14, and 28 days to find the advancement in the compressive strength of concrete. The outcomes from the experiment showed that the solid with glass powder could expand the workability and compressive strength of the concrete. Bhagyasri et al. (2016) [21] carried out a research in which cement was partially replaced by 90 µm glass powder in concrete. As glass powder exhibit pozzolana properties so it was utilized as a partial substitution of cement in concrete. To study different mechanical properties for example compressive strength, flexural quality and Modulus of elasticity of concrete with part of glass powder in the concrete. Different specimens were casted using M20 grade concrete resolved with various percentages of glass powder i.e. 0%, 10%, 20%, 30% and 40%. The specimens were tested at different age of 7days and 28 days. The results of the test conducted in the laboratory showed that the maximum compressive was observed at 20% of glass powder in concrete. Additionally quality of the cement was tested by the UPV test. The outcomes show that the solid with utilizing waste glass powder could enhance the strength and quality of cement. Jangid and Saoji et al. (2014) [24] did a research work on replacing the cement with waste glass powder which act as a filler material instead of cement which takes some part in response to the reaction at the time of hydration. When waste glass was brought to fine powder it starts exhibiting pozzolanic properties as it contains SiO2 and accordingly upto some extent glass powder can be utilized in concrete and contribute quality improvement. In the test Glass powder was added to the specimens at different rate from 0 to 40%, at the interim of 5% and examined for its compressive, tensile and flexural strength upto 60 days and were contrasted with those of regular cement. From the results it was concluded that maximum strength was acquired when 20% concrete was replaced by waste glass powder.

Use of Waste Glass as Partial Replacement in Concrete

Malik et al. (2013) [13] addressed the issues of ecological and financial challenges faced by the cement industry by utilizing waste glass as partial substitution of fine aggregates in concrete. Various samples were prepared with different concentration of glass as 10%, 20%, 30% and 40% by weight in the M-25 grade concrete. The samples were tested for compressibility strength, splitting tensile strength and density at 28 days of curing age. The outcomes from the result were compared with the normal concrete. The specimens with the glass showed better results in terms of compressive strength upto 30% replacement of fine aggregates by weight for particle size of 0.1-1.18 mm. The specimens with glass content also proved to be more economical and environment friendly. Ramana and Samdani et al. (2013) [14] studied the effects of replacing fine aggregates of sand with waste glass in the extents of 0%, 5%, 10%, 15%, 20%, 25% and 30%. Different mechanical properties like compressive strength, split tensile strength and flexural strength were surveyed in this paper. The results obtained from the laboratory tests were noted and compared with the conventional concrete. It was observed from the results that upto 15% replacement of fine aggregates by crushed glass there was increase in the mechanical properties and decreases as fine aggregates replacement by crushed glass reaches upto 30%. Dabiri et al. (2018) [28] carried out this study to find the impacts on the compressive strength and moreover the effects on the weight of the concrete by substituting the concrete aggregates with waste glass particle. To accomplish the objective 27 cubic specimens were made; out of which 6 specimens were made of normal concrete, while in the rest of the specimens glass particles were mixed in different proportions. Micro-silica was added to the cubes containing glass to suppress the Alkali Silica reaction (ASR). From the test results it was demonstrated that replacing aggregates with glass particles over 30% leads to increase in the compressive strength. The weight of the concrete remains nearly same for majority of the samples. From the outcomes it could be concluded that the ideal proportion for replacing aggregates with glass particle is 50%. Ganiron Jr. et al. (2014) [25] conducted this experimental study in order to find the alternative for replacing coarse aggregates in the concrete mixture. In this study crushed glass bottles were utilized at the place of coarse aggregates and its impact on the physical and mechanical properties of the mixture were noted. The experimental outcomes showed that optimum replacement of coarse aggregates with recycled glass bottles is upto 10% weight of coarse aggregates and a mixture design of 5% weight addition to the concrete mix provide the desirable results for compressive strengths. Through the experiment it was proved that coarse aggregates can be effectively replaced by the recycled glass bottles. Turgut and Yahlizde (2009) [17] conducted their experimental study by replacing the Fine Aggregates (FA) of concrete mixture by various levels of Fine glass (FG) and Coarse Glass (CG) and researching the physical and mechanical properties of the cubes. The results from the FG and CG replacement were compared to each other. The values of various properties like compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the samples were observed and noted at 20% FG replacement. Their values were 69%, 90%, 47% and 15% more in comparison to the normal concrete sample. From the results it was also concluded that at 20% replacement level by weight of FG suppresses the alkali-silica reaction (ASR) in the concrete. Kavyateja et al. (2016) [26] did their study on examining the replacement of fine particles by the squashed glass. The control mixing proportion of 1:1.5:3 grouped by volume with water bond proportion of 0.5. The samples were prepared with substitution rate varied from 0% to 40% at a interval of 10%. To analyze the compressive characteristics of concrete samples of sizes 150mm x 150mm x 150mm were casted and examined at 3 days, 7 days, 28 days, 56days and 90 days. From the experimental results it was found that the compressive strength increases up to 20% substitution level and at 30%, 40% substitution level it goes on decreasing. From split tensile strength test it was also concluded that Split tensile strength goes on decreasing with increasing glass content. Elaiyarasu et al. (2015) [27] did a research work on investigating the effects on strength of concrete when recycles glass bottles were used as an alternative coarse aggregate. From the test results it was proved that glass replaced aggregates shows better results in strength and more economical than conventional concrete.

Use of Glass Powder and Aggregates as Partial Replacement in Concrete

Tang et al. (2016) [15] carried out their research with aim to use recycled concrete aggregates (RCA) in Self Compacting Concrete (SCC) which possibly decrease both the natural effect and economical cost of concrete. The work introduced in this paper examines the quality, strength and break properties of SCC's containing RCA content from 0% to 100% at an interim of 25%. The test results showed that at RCA use levels of 25% to50% have very little or no negative effect on the strength, workability, and breakage properties. Except for slight decrease in the young's modulus. With further increase in RCA content beyond 50% its fracture energy decreases. Yahia et al. (2017) [20] conducted an experimental study on the use of fly ash and waste glass powders as a partial replacement in the concrete to test the enhancement in the workability and strength of the concrete. In this experiment material from Jaresh city was utilized. Based on the laboratory tests they concluded that by adding 10% fly ash or waste glass results in a significant increase in the compressive strength and workability of the concrete and addition of fly ash or waste glass content by more than 20% leads to decrease in the compressive strength of concrete. Kou and Poon, (2008) [29] did their research on studying the impacts of using recycled glass (RG) cullet on the properties of self-compacting concrete (SCC). RG was utilized as replacement for the sand in the extents of 10%, 20%, and 30% and adding 10mm granite powder (5%, 10% and 15%) in casting of the SCC concrete mixes. From the experimental results it was concluded that the properties like slump flow, blocking ratio, air content of the RG-SCC mixes increases with increasing Recycled glass content upto certain limit after passing the limit properties like compressive strength, tensile splitting strength and static modulus of elasticity starts decreasing. The outcomes demonstrated that it is possible to use SCC with Recycled Glass cullet. Tariq et al. (2016) [16] investigated the effects of alteration of the superplasticizer (SP) in Self-compacting concrete (SCC) mixture containing waste glass powder of varying sizes as concrete substitutes. To examine the variation three glass measure ranges (10µm, 20µm and 40µm) were analyzed. The experimental results indicated that the finer glass is affected more by the SP dosage in contrast to the coarser glass. With increasing SP dosage compressive strength also increases up to certain level further increase in SP dosage leads to strength loss due to microstructural damage. 10µm glass substituted at a 30% substitution rate gave the most comparable results to Class F Fly ash concrete. Lavanya and Karuppasamy, (2016) [23] used the glass powder and granite powder in the concrete. The strength of the concrete was analyzed and compared with the normal concrete after curing period of 7, 14 and 28 days. The M20, M30, and M40 grade concrete was utilized for this experimental purpose. Through the experimental results it was concluded that glass powder and granite powder can be utilized as an alternate material in the concrete reducing the cement consumption and cost of construction as compared to conventional concrete. The maximum compressive strength was obtained at replacement level of 20% for Glass powder and 25% of Granite powder in all grades of concrete. Batayneh et al. (2006) [22] carried out the research on substituting the recycled waste materials in the ordinary Portland cement concrete (OPC). The waste Materials reused in this examination comprises of glass, plastics, and demolished concrete. Ground plastics and Glass were utilized to substitute the 20% of fine aggregates in concrete mixture while demolished concrete was utilized to substitute 20% of coarse particles of the concrete. To assess these substitutions and their impacts on OPC mixture various tests were conducted. These tests included workability, unit weight, and compressive strength, flexural and indirect tensile strength. The fundamental discoveries of this research uncovered that the three kinds of waste materials can be reused effectively as substitutes for sand and coarse aggregates in concrete mixture.

CONCLUSIONS

From the study of work presented in the various papers, it was observed that waste glass, glass powder and glass powder with aggregates can be successfully utilized in the partial replacements of fine and coarse aggregates in the concrete. Out of the three replacements in the ingredients of the concrete, glass powder was found to be most suitable for the structural applications. The results demonstrated that utilization of glass powder might increase the compressive strength, flexural strength, workability and tensile strength of the concrete. The maximum compressive strength may be obtained at 20% replacements of fine aggregates with glass powder. Moreover, the concrete containing glass powder will also prove to be economical and environment friendly as compared to conventional concrete. So, a detailed study will be undertaken in the nominal concrete with the glass powder as partial replacement.

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Використання відходів скла в бетоні: Огляд

Оксана Бердник, Сергій Виговський

Бетон є широко використовуваним будівельним матеріалом в сучасній промисловості. Бетон складається з цементу, дрібних і крупних заповнювачів. Бетон міцний на стиск і слабкий на розтяг. Крім того, цементна промисловість викидає в атмосферу Землі в середньому 7% парникових газів, що призводить до глобального потепління. Щоб усунути ці негативні наслідки для навколишнього середовища, проводяться широкі дослідження використання замінників цементу з використанням багатьох відходів (наприклад, відходів скла, пластику, летючої золи тощо) та побічних продуктів промисловості. Відходи скла є матеріалом, який не піддається біологічному розкладанню, і утилізація відходів скла на землю призводить до забруднення ґрунту. Таким чином, щоб уникнути цих проблем із відходами скла, можна використовувати як часткову заміну грубих і дрібних заповнювачів. У бетон можна додати скло, частково замінивши будь-який з інгредієнтів у кількох формах. Скло можна додавати у подрібненому вигляді або у вигляді порошку разом із додаванням домішок-пластифікаторів або без додавання будь-яких альтернативних матеріалів у номінальний бетон. Відповідно, у цій статті було проведено дослідження щодо різних аспектів використання скла, щоб включити його до складу бетону як інгредієнта, щоб можна було досягти найкращого можливого використання скла та використовувати його в бетоні з частковими замінами.

Ключові слова: відходи, скляний порошок, бетон, домішки, заповнювач, заміна цементу, часткова заміна.