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Contents

Use of Crushed Waste Glass (CWG) for Partial Replacement of Fine Aggregate in Concrete Production: A Review

Akash Johari and Kedar Sharma

1 Introduction

Glass is one of the most commonly used materials in the construction, electronics, automobile, packing and ornamental industry. Archeologists find the earliest evidence of man-made glass from Mosopotimia for 3500 BC. There are two commonly used methods for glass production: (i) float glass process for sheet glass and (ii) glass blowing process for bottles and other containers. The major ingredients of glass manufacturing are sand or silica, sodium carbonate, lime or calcium oxide, additives (lead, boron, lanthanum oxide, and iron), cullets or pieces of broken glasses and color additives to give different colors [1]. Various types of glass with different ratios of major ingredients with their common uses is presented in Table 1.

The International Energy Agency reported that 130 million tonnes of glass were manufactured worldwide in 2007 [2]. As today's market for glass products rises, the volume of waste glass (WG) will increase [3–5] in the future. Chemical incompatibility does not permit reuse of mixed glass and problems resulting from the variations in malting temperature in each form of material, just 5 g of non-recyclable material can contaminate a tonne of recyclable glass [5].

Concrete is one of the most used man-made materials in the construction industry. Its production is an energy consuming process and its contribution in greenhouse gases emission is around 5–8% [6]. Any effort in reduction of the natural material (aggregate or sand) or possibility to increase the strength is a contribution toward reduction in greenhouse gases. Use of waste glass in concrete started in 1960 and

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Table 1 Types of glasses and common uses

Type of glass	Common uses
Silica glass	Used for high temperature application
Soda lime glass	Used for domestic purpose, window panels, plate glass, light bulb, and containers
Leaded glass	Making shields for protection against gamma radiations optical instruments, neon signs
Borosilicate glass	Laboratory wares, cooking utensils, glass piping

many researchers conducted experiments to find the strength of the concrete with various proportions of waste glass.

In the present study, the results of previous studies in which various proportions of waste glass were used are compiled.

2 Properties of Glass

Transparency, heat tolerance, pressure and breakage resistance ability, and chemical resistance are main features of glass [1]. Glass has quite high tensile strength and high elasticity. However, all properties of glass depend on the compositions of main ingredients and types of manufacturing process. Glasses have low ductility and low conductivity, and due to their inertness and non-reactivity with other liquids, they are ideal materials for storage of chemicals [7].

3 Problems Related to Land Filling of Glass

Due to increase in environmental concern, a properly managed landfill is required for most of the cities. Disposal of waste glass through landfills has some major challenges. It is a non-biodegradable material and hence after a long time also it remains idle in landfills. It is also not flammable and hence cannot be used as fuel like plastic waste. The cathode ray tube (CRT) is a vacuum tube that contains one or two electron arms and a phosphorescent light that is used to display pictures. The electron beam on the screen is modulated, stimulated, and deflected in order to generate images. Recent advances have moved from traditional CRT to liquid crystal display (LCD) panel screens. LCD is a flat panel monitor or other electronically modulated optical system which utilizes the light modulating properties of liquid crystals coupled with polarizers. The LCD contains 85–87, 12.7–14, and 0.12–0.14% glass, polymer, and liquid crystal, respectively [8]. SiO_2 is a major chemical component of liquid crystal glass waste [9]. Liquid crystal consists of a liquid crystal, indium tin oxide (ITO) conductive glass, and black matrix (chromium oxide) glass substrates. Liquid crystal

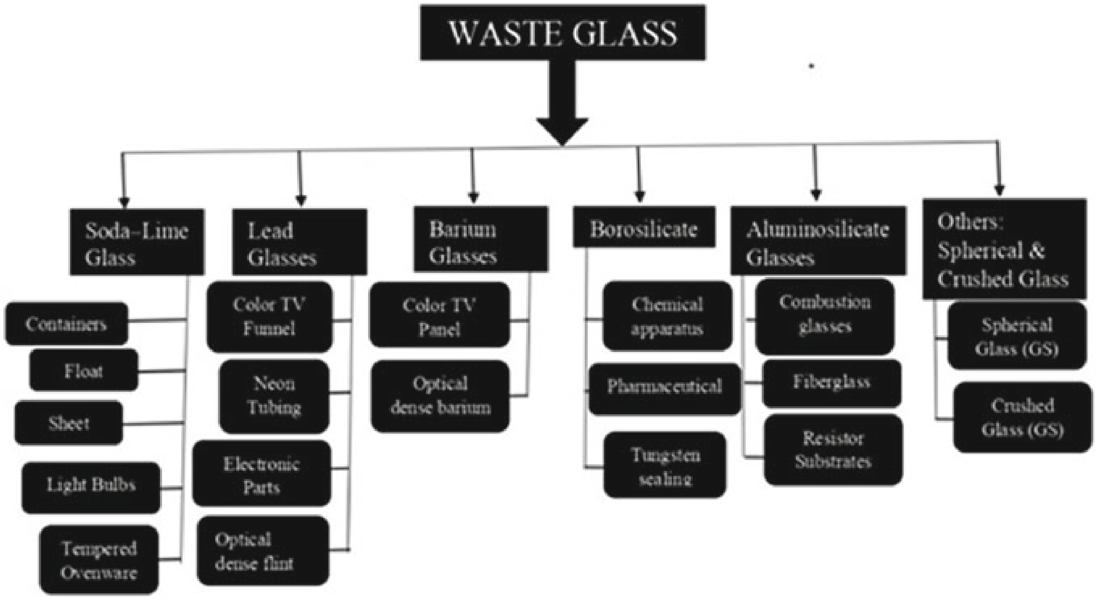

Fig. 1 Classification of waste glass

has a solid-to-liquid intermediate condition [9]. LCD panels are widely used in LCD monitors, laptops, tablets, mobile phones, televisions, and public display applications. The service life of the LCD notebook and TV is 3–5, 8–10 years, respectively [10]. CRT and LCD glasses are also included in the waste glass. A safe disposal of these glasses is necessary due to their toxic properties. Classification of waste glass is presented in Fig. 1.

The USA Characteristic protection office provided 10.37 million tons of glass in 2013 for diet and beverage holders in a large encouragement of metropolitan spreads [11]. 2.78 million tons of toxic material have been removed from usage, which represent the 27% of produced glass. The European Union produced 1.5 million tons of glass waste destruction and refurbishment in 2013 [12] and a couple of 15.9 million tons of bundling squander [13]. The European Union has recovered 73% of glass containers, with Denmark, Belgium, Luxembourg, and Germany, among the top producers in 2015 [14, 15].

Critical audits on the issues of CRT waste glass were conducted by Pauzi [16], Yao et al. [17], Rashad [18], and Adie [19]. Zhao and Poon [20], anticipate CRT glass to be six times bigger by 2050 than it is now. It is reported in literature that in 2002 UK alone produced 104,532 tons of CRT glass from which 69,000 and 26,000 tons were contributed by televisions and computer monitors, respectively [21]. Thailand also produced 1.9 million televisions, 0.75 million computers, and 0.55 million monitors 2007. About 1.5 million televisions and 1.05 million computers were discarded in 2010 [22]. Hong Kong requires 6 million computers, and about 20% of them are updated yearly. Despite the extensive usage of flat screen TVs and displays for plasma/LCD/LED, it is projected that more than 0.49 TV sets and CRT displays are removed from households in a year [23].

Table 2 Glass reclamation rate of different nations

S. No.	Reference	Country	Reclamation rate in 2010 (%)
1.	[15]	Belgium	96
2.		Switzerland	94
3.		Luxembourg	93
4.		Sweden	91
5.		Netherlands	91
6.		Norway	89
7.		Germany	82
8.		Italy	74
9.		France	67
10.		United Kingdom	61
11.		Spain	57
12.	[27]	Australia	34
13.	[15]	USA	33

The total glass reclamation rate of different nations is provided in Table 2. The LCD glass can be used in other items, such as glass, ceramics [24], water-absorbed tiles [25], and cement substitution in cement mortar [9, 25, 26]. Mix use of WG with CRT and TCD glass in concrete production partially solves the issues regarding safe disposal of these materials.

4 Crushed Waste Glass Used in Concrete Production

In 2010, about 12 million tons of concrete were reported to have been manufactured worldwide [27, 28]. Concrete consists of aggregates, cement, and water, along with chemicals to strengthen different properties. In the last few years, numerous experiments have evaluated the impact of CWG as an optimal composite substitute for certain special products. The efficiency of concrete is measured on the basis of mechanical properties including shrinkage and crushing, compressive strength, tensile strength, flexure strength, and elasticity modulus. The gradation of fine aggregate (sand) and CWG is presented in Table 3.

4.1 Dry Density

Dry density is an indirect indicator of the strength of the materials.

Abdullah [30] reported that the dry density of concrete consisting of 5, 15, and 20% of CWG was lower than the target. Decreased dry density could be attributed to

Table 3 Gradation of the accumulated sand and waste material [29]

Sieve size		4.75 mm	2.36 mm	1.18 mm	600 µm	425 µm	300 µm	150 µm	75 µm
Accumulated passing through (%)	Sand	100	94	72	48	37	23	4	0.4
	Crushed waste glass	100	100	100	56	41	25	8	2

a strong specific gravity of natural aggregates compared to glass and a lower specific gravity of sand. Adaway and Wang [29] reported that concrete mix with 15% of CWG had a higher dry density in comparison to original concrete, whereas all other crushed waste glass had a lower dry density than recorded.

4.2 Workability of the Concrete

Slump test is used to measure the workability of concrete. The lack of concrete workability results from the usage of fine WG aggregates in a concrete mix. For this, the conclusions of the literature analyzed are quite inconsistent.

Topcu [31] reported that concrete comprising 15, 30, 45, and 60% of CWG and the slump levels were decreased. Malik [32] reported that concrete composed of 10, 20, 30, and 40% crushed waste glass and slump levels were increased. Abdullah [30] reported that concrete comprising 5, 15, and 20% of CWG were decreased. Adaway and Wang [29] reported that concrete with 15 and 25 of CWG exhibited slump level reduction while concrete with 20, 30, and 40% slump level increases growth. Nagar and Bhargava [33] reported that slump level is unchanged up to 30% and reduction in slump level that concrete comprising 35% or more of CWG. Jain [34] reported that concrete containing 5, 10, and 15% of CWG had decreased slump levels; however, concrete containing 20 and 25% slump level increases.

4.3 Compressive Strength

As mentioned earlier cement, coarse aggregate and fine aggregates are major ingredients of concrete. The researchers did experiments to replace these natural ingredients with some of the waste materials. Compressive strength is the most common indicator to show the improvement in the quality of concrete. Generally it measures for 7 and 28 days. 14 days strength is used for removing the shuttering from the structure. All the results discussed in the upcoming sections are in comparison to the concrete with natural ingredients. However, the researchers used various compositions of natural ingredients and hence original strength may vary. For the comparison purpose, percent increase or decrease in original strength is used in the present study.

4.4 Tolerance for 7 Days

Oliveira [35] reported that higher rates of compressive strength were developed for concrete comprising up to 100% of CWG. Gautam [36] observed that concrete containing up to 50% CWG exhibited higher compressive strength values. Malik [32] observed that concrete containing up to 30% CWG exhibited compressive strength

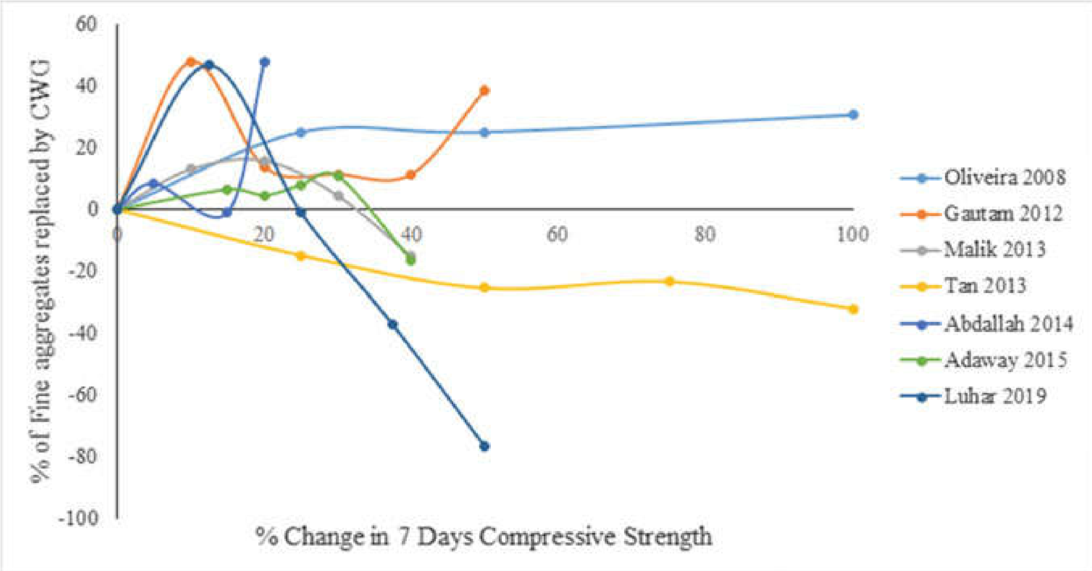

Fig. 2 Effect of replacement of fine aggregate on 7 days compressive strength

values higher, though concrete has experienced a decline in compressive strength with a replacement rate of more than 30%. Tan [37] observed that concrete containing up to 100% underwent a reduction in compressive strength. Abdullah [30] reported that concrete comprising 5 and 20% CWG demonstrated higher levels of compressive strength, however concrete with a substitution content of 15% CWG suffered a decrease in compressive strength. Adaway and Wang [29] reported that concrete up to 30% of CWG had higher compressive strength, however its value decreased when CWG is higher than 30%. Luhar [38] reported that concrete with up to 12.5% CWG had higher compressive strength levels, whereas concrete with a replacement standard over 12.5% had a decrease in compressive strength (Fig. 2).

4.5 Tolerance for 28 Days

Park [38] reported that concrete containing up to 50% of CWG had higher rates of compressive strength, whereas concrete with a substitute amount of over 50% had lower compressive strength. Topcu [31] reported that concrete containing up to 60% underwent a reduction in compressive strength. Oliveira [35] reported that concrete containing up to 100% CWG exhibited compressive strength values higher. Targut [40] reported that concrete made of up to 30% of shattered waste glass displayed higher compressive strength values. Gautam [36] reported that concrete containing up to 20% CWG exhibited compressive strength values higher, whereas concrete with a substitution amount of more than 20% suffered a decrease in compressive strength. Malik [32] reported that concrete containing up to 30% CWG demonstrated higher compressive strength values, whereas concrete with a substitution percentage greater than 30% decreased compressive strength. Tan Kiang [37] reported that concrete

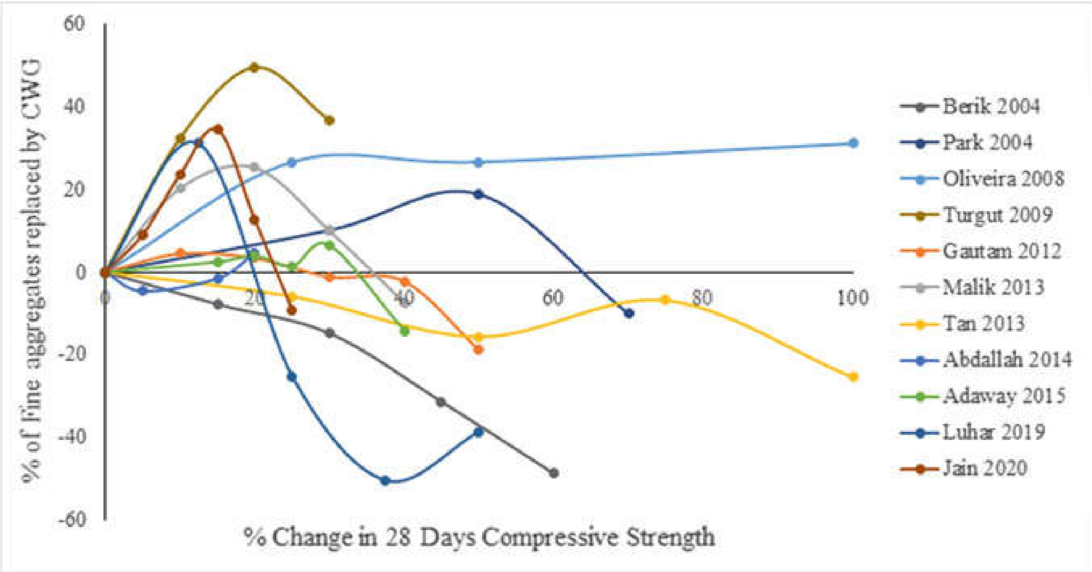

Fig. 3 Effect of replacement of fine aggregate on 28 days compressive strength

containing up to 100% underwent a reduction in compressive strength. Abdullah [30] reported that concrete comprising 20% CWG had higher compressive strength levels, whereas concrete with a replacement ratio of less than 20% had lower compressive strength. Adaway and Wang [29] reported that concrete comprising up to 30% of CWG had higher compressive strength levels whereas concrete with a substitute percent of more than 30% had lower compressive strength. Luhar [38] reported that concrete with CWG up to 12.5% had higher compressive strength ratings, whereas concrete with replacement levels above 12.5% had lower compressive tolerance. Jain [35] reported that concrete containing up to 20% CWG exhibited compressive strength values higher, while concrete has experienced a decrease in compressive strength with a replacement number of more than 20%. The original strength of concrete is 23.5, 34.5, 45, 23.4, 30, 28.1, 51, 32.5, 55, 11.9, 27.5 MPa for Bekir (2004), Park (2004), Olivera (2008), Turgut (2009), Gautam (2012), Malik (2013), Tan (2013), Abdallah (2014), Adaway (2015), Luhar (2019), Jain (2020), respectively (Fig. 3).

4.6 Tensile Strength

It is a fact that the tensile strength of concrete is very low in comparison to compressive strength and hence not used as a measure design criteria for design mixes. However, a nominal tensile strength is desirable for concrete work. Only 28 days split tensile strength is reported in the present review paper.

Some of the specimens of Topcu [31] and Malik [32] reported splitting tensile strength lower than the regulation. However, concrete specimens of Park [39], Targut [40], and Abdullah [30] reported the division's tensile strength greater than normal.

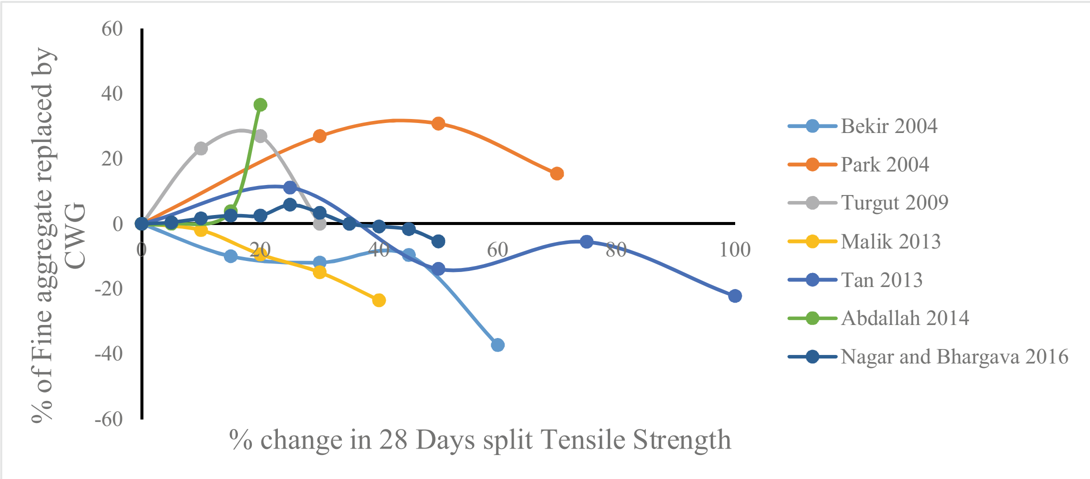

Fig. 4 Effect of replacement of fine aggregate on 28 days split tensile strength

Tan [37] reported that concrete, containing up to 25% of CWG, has demonstrated higher levels of shattering tensile strength, whereas concrete with a replacement quantity has reduced tensile strength by 25%. Nagar and Bhargava [33] also obtained similar results and find that after 25% replacement of CWG, tensile strength again decreases (Fig. 4).

4.7 Flexural Strength

Flexural strength is used when concrete is used for beams. Only 28 days flexural strength is reported in the present review paper.

Park [38] reported that concrete containing CWG up to 50% had a higher flexural strength, however when it increases to more than 50%, flexural strength decreases. Topcu [31] reported that with 15 and 25% CWG content, concrete has higher flexural strength, however, if it increases more than 30–60% it reduces flexural strength. Targut [40] reported this limit to 20% of CWG. It increases up to 20% and then it decreases. Tan [37] reported a lower flexural strength of concrete with CWG. Abdullah [30] reported reverse results and found that up to 5% of CWG, it reduces and then increases with further increase in percentage of CWG (Fig. 5).

5 Summary and Conclusion

Reuse of CWG as building material is an efficient way to decrease the volume of glass disposed of in landfills. It always reduces the use of raw resources and the impact of the construction industry on the environment. In general, the workability of concrete mixtures using CWG as a partial substitute for fine aggregates was lower

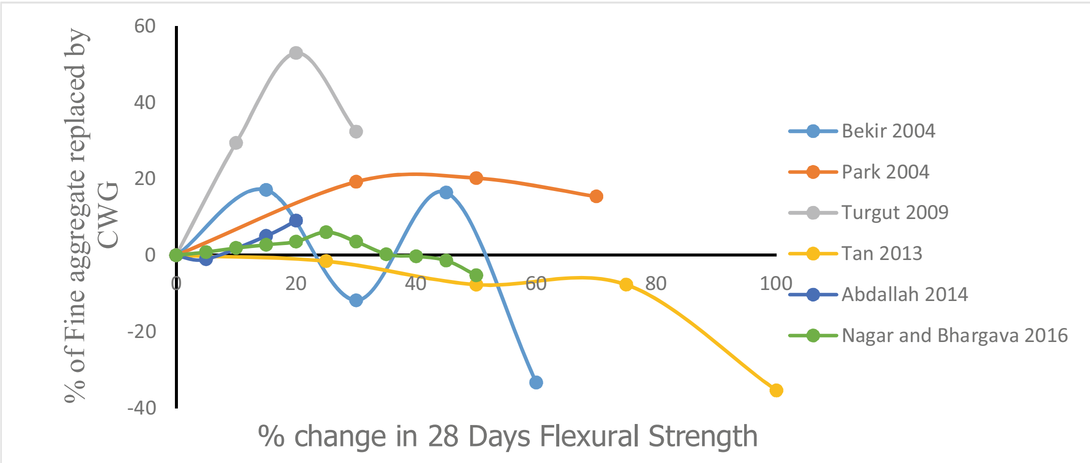

Fig. 5 Effect of replacement of fine aggregate on 28 days flexural strength

than for specimens containing natural aggregates. Almost zero water absorption by glass particles is the probable reason. It is also observed that the water from CWG concrete dries out and creates a gap as concrete is put flat. The dry density of concrete mixtures made up of CWG as a partial replacement for fine aggregates was lower than that of standard aggregates cantered on collections. The dry density of the concrete depends on the quantity and aggregates of the CWG, the amount of air produced and the cement. It is reported by most of the researchers that the compressive, tensile, and flexural strength of concrete mixtures was increased by partially substituting natural fine aggregate by CWG. However, it has a limiting value of substitution and once it reaches the optimum proportion it again reduces. In few studies, it is reported that this strength may be lower than original concrete strength with natural aggregates. The limiting proportion of CWG is not uniform in the previous studies. Some researchers also pointed out that CWG aggregates were poorer than natural aggregates. With these inconsistencies in experimental results, use of CWG in concrete mixes minimize the adverse effect of use of natural materials.

6 Future Scope

Partial replacement of fine aggregate with CWG in concrete is a good solution for the safe disposal of waste glass. However, in the previous studies a uniform mix design was not used by the researchers. In future, it can be suggested to use a similar concrete mix for replacement of fine sand so that it can be compared with same base values.

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