A REVIEW ON RECYCLING OF WASTE GLASS IN CONSTRUCTION INDUSTRY

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Abstract: *The utilization of many industrial byproducts in the construction industry is now well-developed as it helps in improving the sustainability in two ways. First, reuse of the materials which otherwise will burden the environment and will be occupying scarce land resource. Second, it minimizes the degradation of land and the environment as a result of comparatively less digging. Quantities of waste glass have been on the rise in recent years due to an increase in industrialization and the rapid improvement in the standard of living. Unfortunately, the majority of waste glass is not being recycled but rather abandoned, and is therefore the cause of certain serious problems such as the waste of natural resources and environmental pollution. Thus, efforts have been made during the last decade on exploring the possibility of reusing waste glass as a construction material. Waste glasses can be used as raw materials for cement production as siliceous sources. Ground glass powders exhibit very good pozzolanic reactivity and can be used as cement replacement. The crushed glasses can also use as aggregates for Portland cement concrete. The present paper reviewed the different studies regarding use of waste glass in concrete and finds their effect on the properties of concrete.*

Keywords: *Concrete**,** Recycling**,** Waste glass*

INTRODUCTION

Glass in general is a highly transparent material formed by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperatures followed by cooling during which solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing. Glass has been indispensable to man's life due to such properties as pliability to take any shape with ease, bright surface, resistance to abrasion, safety and durability. The utility ranges of the glass increase the amount of the waste glass (WG). The WG can be recycled into new glass. However, not all used glass can be recycled into newglass because of impurities, cost or mixed colors. Nonrecyclable waste glass constitutes a problem for solid waste disposal in many municipalities. The current practice is still to landfill most of the nonrecyclable glass. Since the glass is not biodegradable, landfills do not provide an environment-friendly solution [1]. Consequently, there is a strong need to utilize waste glasses. Traditionally, most nonrecyclable mixed-color broken glasses are coming from the bottling industry. In addition, the recently initiated business of recycling mercury-containing fluorescent lamps also produces a large quantity of nonrecyclable waste glass. The fluorescent lamp recycling facility crushes the fluorescent lamps, separates the metal caps, and recovers mercury. For 55,000 tubes recycled, approximately 30 m^3 of waste glass will be generated. In the future, with the environmental law being strictly enforced and with the increasing use of fluorescent lighting systems for energy efficiency, it is expected that more nonrecyclable waste glass will be accumulated from the fluorescent lamp recycling business [2]. Foreign countries have long been taking much effort to recycle waste glass bottles. A bottle recovery system, through which empty bottles previously containing alcoholic beverages, refreshing beverages, condiments, milk, etc. are collected, washed, and reused, has already been established. In addition, broken bottles and bottles previously containing chemicals, cosmetics, etc. are melted down to be reused or crushed and turned into paving material, block material, glass marble, glass tile, glass fiber, lightweight blowing agents, etc [3–4].

Use of recycled materials in construction is among the most attractive options because of the large quantity, low quality requirements and widespread sites of construction. The main applications include a partial replacement for aggregate in asphalt concrete and cement concrete. Recently, many studies have focused on the uses of wastes glassed as aggregates for cement concrete or as cement replacements [5-7]. The present paper reviewed the different applications of waste glass in construction industry.

PHYSICAL AND CHEMICAL PROPERTIES OF GLASSES

The more common types of silicate glasses are vitreous silica, soda-lime glasses, borosilicate glasses, lead glasses, barium glasses, and aluminosilicate glasses. Vitreous silica glass has very low thermal expansion, is very hard, and resists high temperatures (1000–1500 °C). It is also the most resistant against weathering. Soda-lime glass is transparent, easily formed and most suitable for window. It has a high thermal expansion and poor resistance to heat (500–

600 °C). Borosilicate glasses stand heat expansion much better than window glass. Used for chemical glassware, cooking glass, car head lamps, etc. Borosilicate glasses have as main constituent's silica and boron oxide. They have fairly low coefficients of thermal expansion is 3.25×10^{-6}/°C as compared to about 9×10^{-6}/°C for a typical soda-lime glass. The typical compositions of different types for different applications are listed in Table 1. In chemical compositions of soda-lime glass shows SiO_2 around 73% which is good for a pozolanic material. Lead glass has also good amount of silica oxide, but due to the high lead content in the glass. This can be potentially leached into the environment. Borosilicate is not commonly used. Thus soda-lime glass can used in construction industry.

Table 1: Chemical composition of selected commercial glasses in percentage [8]

Glasses and uses	**SiO_2**	**Al_2O_3**	**Na_2O**	**K_2O**	**MgO**	**CaO**
Soda-lime glasses						
Containers	66-75	0.7-7	12-16	0.1-3	0.1-5	6-12
Float	73-74		13.5-15	0.2	3.6-3.8	8.7-8.9
Sheet	71-73	0.5-1.5	12-15		1.5-3.5	8-10
Light bulbs	73	1	17		4	5
Tempered ovenware	75	1.5	14			9.5
Borosilicate						
Chemical apparatus	81	2	4			
Pharmaceutical	72	6	7	1		
Tungsten sealing	74	1	4			
Lead glasses						
Color TV funnel	54	2	4	9		
Neon tubing	63	1	8	6		
Electronic parts	56	2	4	9		
Optical dense flint	32		1	2		
Barium glasses						
Color TV panel	65	2	7	9	2	2
Optical dense barium crown	36	4				
Aluminosilicate glasses						
Combustion tubes	62	17	1		7	8
Fiberglass	64.5	24.5	0.5		10.5	
Resistor substrates	57	16			7	10

USE OF WASTE GLASS IN CEMENT PRODUCTION

The waste glass can be used in the production of cement due to SiO_2 component in the glass. However the alkali component in the glass results increase in alkali in cement. It is well known that alkalis has adverse effect on the production of cement, but waste glass as a raw material in cement production has no of advantages. Many researchers have work on the suitability of waste glass in cement production.

An innovative approach of using waste glass in cement production was proposed by Chen [9] in a laboratory and cement production plant. The laboratory characterization of 32 types of glass show that the chemical composition of glass does not vary significantly with its color or origin but depends on its application. The alkali content of glass, a major concern for cement production varies from 0 to 22%. The SO_3 content of the clinker is comparable with that obtained without the loading of glass. The alkaline content shows a slight increase but still within three times the standard deviation obtained from the statistical data of the past year. The detailed analysis of the quality of the cement product shows that there is not any significant impact of glass for the feeding rate tested. In other study the effects of the glass in cement raw mix on clinker burning were investigated [10]. The experimental results show that the addition of the glass into cement raw mix results in the formation of more liquid phase between 950°C to 1250°C compared with conventional raw meals. Decreases C_3S content in the clinker and increases NC_8A_3 content, which leads to flash setting and poor strength development of the cement. Therefore, it is necessary to increase the SG value [$SG=SO_3 \bullet 100\ \%/(1.292\ K_2O+0.85\ Na_2O)$] of the clinker when the glass is present in the raw mix.

USE OF WASTE GLASSES AS CEMENT CONCRETE AGGREGATE

The use of waste glass as aggregate in concrete has also been studied by many researchers. The deleterious alkali- silica reaction (ASR) has been a major concern with such concrete [11]. Meyer et al [12], report some of the possible measures available to mitigate ASR. These included grinding glasses to a particle size less than 300 lm, use of mineral admixtures, using alkali-resistant glass, sealing concrete to keep it dry or using low alkali cement. However Ahmad and Aimin [13] concluded that up to 50% of both fine and coarse aggregates could be replaced in concrete by glass aggregates with acceptable strength development. This finding is in general agreement with results obtained by Park et al [14]. Improvements in cullet production methods was shown by Sangha et al [15] to produce concrete that was stronger than that made with natural aggregate in tension and compression when using glass cullet up to replacement levels of 60%. The authors attributed the improved strength to better bonding between glass cullet and cement matrix than that achieved with natural aggregate. The process used for producing recycled glass aggregate used in this study has been described elsewhere, Sangha et al [15]. The resulting cullet is free of sharp edges and all the paper, foil, plastic labels and organic impurities that may have been attached to the glass are liberated and separated during the implosion process. It was observed by the authors that the temperature of glass cullet after production remained high for the next 24 h. It was thus considered that concrete made with glass cullet could have significantly different thermal properties. Corinaldesi et al [16] investigated that mechanical properties and microstructures of mortars with 30–70% replacement of fine sand with ground glasses. It was noticed that no deleterious effect could be detected at a macroscopic level due to the reaction between cement paste and ground waste glass with particle size up to 100 micron. On the contrary, a strong improvement of the mortar mechanical performance was detected, due to the positive contribution of the waste glass to the micro-structural properties. The use of waste glasses as aggregates did not have a marked effect on the workability of concrete, but decreased the slump, air content and fresh unit weight [17]. Concrete with glass aggregates would require a higher content of water than conventional aggregates to reach the same workability. The compressive, flexural and indirect tensile strengths as well as Schmidt hardness decrease in proportion to an increase in waste glass aggregates. The strength noticeably decreased when the glass content was more than 20% [17].

USE OF WASTE GLASS AS SUPPLEMENTARY CEMENT REPLACEMENT MATERIAL

Glass is amorphous and contains relatively large amounts of silicon and calcium. Thus it can be claimed that it is pozzolanic or even cementitious in nature, even when it is finely ground. Therefore, glass powder can be considered as a replacement for cement in concrete [18]. The pozzolanic properties of glass are noticeable at particle sizes below approximately 100 mm. Studies by Shi et al [19] showed that not only glass with particle size below 100 mm can have a pozzolanic reactivity but also its effect is greater than fly ash at low level of cement replacement (10-20%). Work by Chen et al [20] revealed that a glass powder with particle size less than 75 mm possessed cementitious capability and improves compressive strength, resistance to sulphate attack and chloride ion penetration, for replacing of cement up to 50%. Idir et al [21] indicated that the pozzolanic activity has a tendency to enhance with finer glass powder. Equivalent or superior compressive strength was attained when using up to 40% of mixed-colour glass powder with a particle size less than 40 mm when compared with control specimens. Shao et al [22] measured strength of the lime–glass mixtures as the pozzolanic index for three glass powders. The strength results indicated that the 38 µm glass satisfied the minimum strength requirement at 7-day test, and attained an increase in strength after additional 21 days of curing in water. The strength of the mixture with 150 µm glass was far below the limit because the size of the glass was too coarse to serve as a pozzolan. The 75-mm glass performed marginally. Its 7-day strength was slightly lower than the threshold value, while its additional 21-day curing in water enhanced the strength to a satisfactory level. Nishikawa et al [23] was found that the strength of cement paste at 90 days increased with the glass content increase up to 25%. The Blaine fineness of the glass powder is about $400m^2/kg$, but no chemical analysis of the glass powder was given. Dyer and Dhir [24] measured the compressive strength development of cement pastes containing white, green, and amber cullet. There is clearly some difference in the strength development of mortars containing different-colored finely ground glass cullets: white and green produce a slight increase in 28-day compressive strengths relative to the glass-free control at replacement levels of around 10%, whereas amber finely ground glass cullet merely achieves similar strengths to the control. The rate of strength gain in mortars containing finely ground glass cullet is noticeably higher between 7 and 28 days compared to the control. This behavior implies that a pozzolanic reaction is occurring.

CONCLUSION

After reviewed the different studies, uses of waste glass in concrete are summarized as follows:

- Waste glasses cans be used as raw materials for cement production as siliceous sources.
- Waste glass containing relatively large quantities of silicon and calcium, and posses' pozzolanic and cementitious nature when it is finely ground. Thus, it can be used as a cement replacement in Portland cement concrete. As expected, its pozzolanic reactivity increases as its finenesses increase.

- The use of crushed glasses as aggregates for Portland cement concrete does have some negative effect on properties of the concrete; however, practicle applicability can still be produced even using 100% crushed glass as aggregates

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