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Research Article

Effect of using Waste Glass on the Fresh Properties and Compressive Strength of Concrete

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Abstract: The application of alternative materials in concrete production is getting importance due to rising awareness about sustainable construction. Among alternate materials, recycled waste glass shows good pozzolanic behavior due to its high silica content which makes it an alternate option of cementitious material in concrete. Other physical properties, like-inert nature, positive response against compression etc. and chemical properties make glass an alternative of fine and coarse aggregate too. A critical review on fresh properties and compressive strength of concrete incorporating waste glass has been described in this study based on various published literatures. It has been found from several studies that if waste glass is added in a proper proportion, it is possible to achieve workable concrete with better strength properties than that of regular concrete. Conventional aggregates of concrete, like-gravel, brick chips, sand and cement are expensive, cause extraction of natural resources and environmental pollution. In this context, it can be said that waste glass may introduce an option of economic and pollution free concrete construction if used in optimum quantity.

Keywords: Alternate construction materials, compressive strength, density, sustainable construction, waste glass, workability

INTRODUCTION

For centuries, glass has been serving as a universal packaging container, holding commodities and today, manufacturers use glass to hold everything from soda to perfume (US EPA, 2012). With time, the increasing use of glass products is resulting in large amounts of waste glass. In 2005, the estimated production of the global glass was 130 Mt. Container glass accounts were approximately fifths and flat glass was approximately one third of the production. The European Union produced approximately 33 Mt of glass, whilst China and USA produced approximately 32 and 20 Mt, respectively (IEA, 2007).

Reuse/recycle and waste reduction are very important elements in a framework of waste management. It helps to conserve natural resources, reduce demand for valuable landfill space, diminish the need of raw materials to make new product, reduce air and water pollution, reduce energy and create new jobs (Chai *et al*., 2013). However, not all used glass can be recycled into new glass because of impurities, cost, or mixed colors (Caijun, 2009). It is necessary to establish new options to utilize recycled waste glass. One important option is to use waste glass as construction materials. Glass is basically a product of the super cooling of a melted liquid mixture consisting primarily of sand (silicon dioxide) and soda ash (sodium carbonate) to a rigid condition, in which the super cooled material, does not crystallize and retains the organization and internal structure of the melted liquid (User Guidelines for Waste and Byproduct Materials in Pavement Construction, 1997). Since 1963, the first study had been carried out on the use of glass chips to produce architectural exposed aggregate for concrete (Chai *et al*., 2013).

With more than 10 billion tons of concrete produced annually, it is considered to be the most important building material (Meyer, 2009). It has been predicted that the world's population will increase from the present-day 6-9 billion by the year 2050 and to 11 billion by the end of the century, which will result in a considerable increase in the demand for water, energy, food, river sources, common goods and services

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(Roskovic and Bjegovic, 2005). Also, the demand for concrete is expected to grow to approximately 18 billion tons a year by 2050 (Mehta and Monteiro, 2006). Consequently, the concrete industry is going to use a considerable amount of natural resources to produce cement and concrete. For this reason, research works are being made on alternative building materials for last years and a significant space is covered by the potential use of waste or recycled materials in concrete (Ahmad, 2002; Ledererova and Grunner, 2006; Jevtic *et al*., 2012; Kou and Xing, 2012; Zain *et al*., 2011; Zhang and Mohan, 1996; Khan *et al*., 2015; Siddique, 2008; Khan *et al*., 2014; Karim *et al*., 2014.).

In order to reduce the dependency on natural resources as well as considering environmental impacts, waste glass could be a worthful ingredient of concrete. Land filling of waste glass requires huge free space and is also expensive. On the other hand glass is non-degradable which means it requires more space than other wastes and it remains in the environment. Besides the economic benefits, reasons which make recycled glass a potential aggregate of concrete are-glass is a unique inert material which can be recycled many times without changing the chemical properties, it is good in compression and it has good insulation properties (Ahmad, 2002). Based on available published literature, this study focuses on fresh and strength properties of concrete incorporating waste glass as an aggregate.

Many studies have been made where waste glass has been used partially as binder material along with regular cementitious aggregates in concrete. Vasudevan and Kanapathypillay (2013) used waste glass powder partially as binder material. It was reported that concrete with waste glass powder has a very high workability from control sample and is possible to achieve 30 MPa of compressive strength. Kumarappan (2013) and Khatib *et al*. (2012) showed that slump value of freshly mixed concrete increases as the glass powder in the mix increases. Density values are almost similar to control mix and at 10% glass powder content the compressive strength of concrete is higher than that of the control mix. Kou and Xing (2012) stated that the flow diameter of concrete decreased with an increase in recycled glass powder and there is a decreasing tendency in early stage of compressive strength and opposite after 28 days. Vandhiyan *et al*. (2013) and Jangid and Saoji (2014) reported that workability decreases as the percentage of glass powder in the mix increases. Compressive Strength increases up to 15-20% of replacement and then declines. Jihwan *et al*. (2014) and Madandoust and Ghavidel (2013), both stated that compressive strength is higher than control mix up to around 10% glass powder replacement.

Waste Glass powder has also been used partially with regular fine aggregate in concrete by several researchers. Wang and Huang (2010) used LCD glass partially with fine aggregate in concrete and reported that slump flow increased and compressive strength decreased with an increase in glass percentage. As per the studies of Ismail and Hashmi (2009), Park *et al*. (2004), Bashar and Ghassan (2008) and Limbachiya (2009), workability reduced with increase in glass percentage. The studies also stated that compressive strength increased to a desired level up to a certain percentage of replacement and then decreased.

Comparatively less studies has been made on waste glass as coarse aggregate in concrete. Serniabat *et al*. (2014) used two types of waste glass as entire replacement of coarse aggregate in concrete and reported that 26.8 MPa compressive strength is possible to achieve with glass. Keryou (2014), Srivastava *et al*. (2014) and Medina *et al*. (2013) used crushed glass partially as coarse aggregate in concrete. It was concluded that slump and fresh density decreases with increasing glass percentage. It was also concluded that a reasonable compressive strength can be achieved with glass replacement of 10-25%. Topcu and Canbaz (2004) stated that slump and fresh density decreases with high percentage of glass content due to the poor geometry of glass. In case of compressive strength, optimum percentage of glass addition is around 15%.

However, it is recognized that waste glass improves several properties of concrete in some extent when added at an optimum percentage. In this regard, various sources of waste glass used by researchers and their chemical properties, fresh and hardened properties of waste glass blended concrete are described in this review study based on the available published literatures and documents.

CHEMICAL COMPOSITION OF WASTE GLASS

Worldwide glass is being produced in many forms. It includes packaging of container glass (bottles, jars), flat glass (Windows, windscreens), bulb glass (light globes), cathode ray tube glass (TV screens, monitors, etc.), all of which have a limited life in the form they are produced and needed to be reused (Ahmad, 2002). Different researchers used waste glass from different sources for their studies. Vasudevan and Kanapathypillay (2013) collected waste glass from disposal area and then grind it to powder. Kou and Xing (2012) used glass powder samples which were derived from recycled glass bottles and passed through a laboratory shaking mill to obtain particles smaller than 0.045 mm. Vandhiyan *et al*. (2013) experimented with green colored glass. The glasses were grounded to powder to make glass powder of size that 100% passes through 90 micron sieve and 50% retained in 75 micron sieve. Jihwan *et al*. (2014) worked with locally available glass powder. The glass powder used in the study of Madandoust and Ghavidel (2013) was obtained from construction waste. Ahmad (2002) used waste glass from glass containers. Bashar and Ghassan (2008) used glass supplied by a glass company. Wang and Huang (2010) collected LCD glass from an electronics company. Ismail and Hashmi (2009) experimented with waste glass of containers (bottles, jars) and flat glass (windows). Park *et al*. (2004) worked with domestic waste glass which is mainly soda-lime series that are widely used for bottles and glass ware in Korea. Limbachiya (2009) used colored beverage glass containers from the materials recovery facilities, restaurants and clubs. Malek *et al*. (2007) used construction field wastes for their research work. Castro and Brito (2013) took waste glass from building and car window panels, washed and treated in a plant. Gautam *et al*. (2012) experimented with demolished waste. Serniabat *et al*. (2014) used waste glass from a television company. The source of glass aggregate used in the research of Keryou (2014) was the waste of windows, collected from local windows glass venders.

Table 1: Glass chemical composition

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Al_2SO_3	Cr_2O_3	TiO_2	B_2O_3	BaO	PbO	Sb_2O_3	SrO	ZrO_2	References	Form in concrete
68.2	10.1	0.242	9.9	2.94	0.229	7.62	0.367										Jihwan *et al*. (2014)	Binder
73.1	1.36	0.67	9.79	3.45	11.1												Madandoust and Ghavidel (2013)	Binder
71.4	1.4	0.2	10.6	2.5	0.5	12.7	0.1										Kou and Xing (2012)	Binder
72.2	1.54	0.48	11.42	0.79	0.43	12.85	0.09										Ahmad (2002)	Binder
72.5	1.06	0.36	8	4.18	0.26	13.1	0.18										Kumarappan (2013)	Binder
72.39	1.47	0.29	11.25	0.54	0.27	13.52	0.07		0.13	0.09							Vandhiyan *et al*. (2013)	Binder
72.5	0.4	0.2	9.7	3.3	0.1	13.7											Jangid and Saoji (2014)	Binder
72.3	1.04	0.17	8.61	3.89	0.52	13.31			<0.05	<0.05							Bashar and Ghassan (2008)	Binder
62.48	16.76	9.41	2.7	0.2	1.37	0.64											Wang and Huang (2010)	FA[1]
67.72	3.4		6.9	6	10.75		0.17										Ismail and Hashmi (2009)	FA
71.3		0.596	12.18		13.07		0.053	2.18	0.44								Park *et al*. (2004)	FA
72.1		0.31	11.52		14.11		0.13	1.74	0.01								Park *et al*. (2004)	FA
73.04		0.04	10.75		13.94		0.22	1.81									Park *et al*. (2004)	FA
72.1	1.78	0.36	10.63	1.26	0.64	12.4			0.09	0.06							Bashar and Ghassan (2008)	FA
70.13	1.76	0.37	12.08	1.55	0.55	14.56			0.01								Limbachiya (2009)	FA
51.392	4.468	0.269	3.164	1.562	7.554	6.411	0.068			0.103	0.3	1.603	20.89	0.223	1.45	0.323	Serniabat *et al*. (2014)	CA[2]
66	21	1	2	0.3	3	2											Medina *et al*. (2013)	CA
70-75	0.5-2.5		5-14	0-4	0-1	12-18											Topcu and Canbaz (2004)	CA
72.61	1.38	0.48	11.7	0.56	0.38	13.12	0.09										Ahmad (2002)	CA+FA
72.8	1.4		4.9	3.4	0.3	16.3					1						Shaoa *et al*. (2000)	Binder
68	7		11	1		12											Nassar and Soroushian (2012)	Binder

1: Fine Aggregate; 2: Coarse Aggregate

Table 2: Chemical composition of Cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	SrO	P_2O_5	Loss on Ignition	References
18.8	4.18	3.76	65.3	2.43	1.1	0.15	3.3				2.8	Jihwan *et al*. (2014)
21.4	5.9	2.4	62.3	3.77			2.3				1.22	Keryou (2014)
21.2	6.27	3.08	63.4	1.85	0.75							Madandoust and Ghavidel (2013)
21	5.9	3.4	64.7	0.9			2.6				1.2	Kou and Xing (2012)
20.7	4.65	3.1	62.9	3.43	0	0	2.4				2.11	Wang and Huang (2010)
30.9	6.75	3.57	47.8	1.3			1.7				6.2	Topcu and Canbaz (2004)
22	5	3	62	2	1		1					Kumarappan (2013)
21.6	5.39	3.39	65.5	1.19			2.8				1	Vandhiyan *et al*. (2013)
20.2	4.7	3	61.9	2.6	0.82	0.19	3.9				1.9	Jangid and Saoji (2014)
20.4	5.63	2.85	64.5	1.09	0.64	0.18		0.27	0.1	0.16		Bashar and Ghassan (2008)
21.1	5.78	3.59	64.4	1.52			2.4				0.89	Ismail and Hashmi (2009)
21.2	5.97	3.34	62.7	2.36	0.81	0.13	2				1.46	Park *et al*. (2004)
21.2	5.47	3.31	62.5	1.97	1.71	0.46	1.9				1.46	Limbachiya (2009)
19.4	5.22		62.1	1.38	0.89	0.36	3.3	0.2	0.8	0.07	0.72	Medina *et al*. (2013)

Medina *et al*. (2013) used recycled aggregate, supplied by a ceramic sanitary ware factory. Topcu and Canbaz (2004) worked with colored soda bottles. Shao *et al*. (2000) used waste glass obtained from recycled fluorescent lamps.

Different chemical compositions of waste glass used by researchers are given in Table 1. The chemical compositions of cement used in several studies are presented in Table 2.

WORKABILITY OF CONCRETE INCORPORATING WASTE GLASS

Waste Glass powder as Binder material: Slump values found by several researchers incorporating waste glass powder as binder material are presented in Table 3. Vasudevan and Kanapathypillay (2013) replaced cement with 10, 15 and 20%, respectively glass powder. It was found that slump value of the control mix is 33 mm and slump of glass concrete increased from 60 mm to 70 mm with increasing percentage of glass powder. As per the studies glass concrete showed more workability than normal concrete. As per the studies of Kumarappan (2013), cement is partially replaced with 10, 20, 30 and 40% glass powder respectively. The slump ranged from around 40 mm for the reference mix to 160 mm at 40% glass powder. Khatib *et al*. (2012) also showed a systematic increase of slump value with glass addition. Kou and Xing (2012) observed during mixing and testing that the flow ability of the fresh concrete had a close relationship with the fineness of the cementitious materials and the aggregate. Vandhiyan *et al*. (2013) stated workability reduced with the replacement which is due to the increase in the surface area of the glass powder and also the angular shape of the glass particles. Jangid and Saoji (2014) showed that slump value ranges from 80 to 100 mm and workability of concrete decreases as percentage of glass powder increases. As per Bashar and Ghassan (2008), there is no significant difference between slump values of control mix and glass mixed concrete. This refers to the texture and shape properties of the glass particles. Chikhalikar and Tande (2012) stated that 20% replacement of cement by waste glass powder gives better workability. As per studies of Nassar and Soroushian (2012) slump is observed to slightly increase with the introduction of milled waste glass. This could be attributed to the fact that glass has low water absorption capacity. The slump of glass concrete mixes is higher than that of corresponding control mixes.

Table 3: Slump of concrete with waste glass as binder material

C[a]: Others[b]: WG[c]	W/B[d] Ratio	Slump (mm)	Flow Dia (mm)	References
Control		33		Vasudevan and Kanapathypillay (2013)
90:0:10		60		Vasudevan and Kanapathypillay (2013)
85:0:15		63		Vasudevan and Kanapathypillay (2013)
80:0:20		70		Vasudevan and Kanapathypillay (2013)
Control	0.5	47		Kumarappan (2013)
90:0:10		60		Kumarappan (2013)
80:0:20		75		Kumarappan (2013)
70:0:30		110		Kumarappan (2013)
60:0:40		160		Kumarappan (2013)
Control	0.5	45		Khatib *et al*. (2012)
90:0:10		60		Khatib *et al*. (2012)
80:0:20		73		Khatib *et al*. (2012)
70:0:30		111		Khatib *et al*. (2012)
60:0:40		160		Khatib *et al*. (2012)
Control	0.15		255	Kou and Xing (2012)
75:10:15			244	Kou and Xing (2012)
60:10:30			232	Kou and Xing (2012)
Control	0.48	100		Jangid and Saoji (2014)
95:0:5		96		Jangid and Saoji (2014)
90:0:10		93		Jangid and Saoji (2014)
85:0:15		89		Jangid and Saoji (2014)
80:0:20		88		Jangid and Saoji (2014)
75:0:25		85		Jangid and Saoji (2014)
70:0:30		82		Jangid and Saoji (2014)
65:0:35		80.5		Jangid and Saoji (2014)
60:0:40		80		Jangid and Saoji (2014)
Control	0.38	120		Bashar and Ghassan (2008)
80:0:20		120		Bashar and Ghassan (2008)
Control	0.45	80		Chikhalikar and Tande (2012)
90:0:10		100		Chikhalikar and Tande (2012)
80:0:20		125		Chikhalikar and Tande (2012)
70:0:30		115		Chikhalikar and Tande (2012)
60:0:40		100		Chikhalikar and Tande (2012)
Control	0.47	70		Nassar and Soroushian (2012)
80:0:20		92		Nassar and Soroushian (2012)
Control	0.62	178		Nassar and Soroushian (2012)
80:0:20		204		Nassar and Soroushian (2012)

a: cement; b: other cementitious material; c: waste glass; d: water/binder ratio

Waste Glass as Fine Aggregate: Slump values found by several researchers incorporating Waste Glass as Fine Aggregate are presented in Table 4. Wang and Huang (2010) used LCD glass partially with fine aggregate in concrete. It was reported that slump flow increased with an increase in glass percentage. For a glass replacement of 10-30%, the slump flow increased from 20 to 100 mm. This tendency could be caused due to the higher compactness of the concrete granular skeleton. Since glass sand is finer than conventional sand, it can fill space between the grains of coarse aggregate in a better way. Ismail and Hashmi (2009) established the tendency of decreasing slump when waste glass ratio increases. These phenomena can be related to the poor geometry of the waste glass, which causes lesser fluidity of the mixes as well as the reduction of fineness modulus. In spite of the decline in the slump values, the waste glass concrete mixes were considered workable as per the study. Park *et al*. (2004) showed a tendency of decreasing slump as the mixing

Table 4: Slump of concrete with waste glass as fine aggregate

S^f : WG	W/B Ratio	Slump (mm)	Slump flow (mm)	References
100:0	0.28		675	Wang and Huang (2010)
90:10	0.28		720	Wang and Huang (2010)
80:20	0.28		765	Wang and Huang (2010)
70:30	0.28		800	Wang and Huang (2010)
100:0	0.28	75		Ismail and Hashmi (2009)
90:10	0.53	57.5		Ismail and Hashmi (2009)
85:15	0.53	52.5		Ismail and Hashmi (2009)
80:20	0.53	50		Ismail and Hashmi (2009)
Control	0.5	130		Park *et al*. (2004) amber
70:30	0.5	105		Park *et al*. (2004) amber
50:50	0.5	88		Park *et al*. (2004) amber
30:70	0.5	80		Park *et al*. (2004) amber
70:30	0.5	100		Park *et al*. (2004) emerland green
50:50	0.5	90		Park *et al*. (2004) emerland green
30:70	0.5	75		Park *et al*. (2004) emerland green
70:30	0.5	95		Park *et al*. (2004) flint
50:50	0.5	85		Park *et al*. (2004) flint
30:70	0.5	71		Park *et al*. (2004) flint
100:0	0.38	120		Bashar and Ghassan (2008)
50:50	0.38	95		Bashar and Ghassan (2008)
0:100	0.38	80		Bashar and Ghassan (2008)
Control	0.52	75		Limbachiya (2009)
85:15	0.52	75		Limbachiya (2009)
80:20	0.52	70		Limbachiya (2009)
70:30	0.52	70		Limbachiya (2009)
50:50	0.52	65		Limbachiya (2009)
Control	0.56	76.3		Malek *et al*. (2007)
95:5	0.56	75.3		Malek *et al*. (2007)
90:10	0.56	74.6		Malek *et al*. (2007)
85:15	0.56	73		Malek *et al*. (2007)
80:20	0.56	72.7		Malek *et al*. (2007)
Control	0.55	127		Castro and Brito (2013)
95:5	0.55	124.5		Castro and Brito (2013)
90:10	0.57	125		Castro and Brito (2013)
80:20	0.58	121.5		Castro and Brito (2013)

f: natural sand

Table 5: Slump of concrete with waste glass as coarse aggregate

G^e : WG	W/B Ratio	Slump (mm)	References
Control	0.5	120	Keryou (2014)
80:20	0.5	110	Keryou (2014)
75:25	0.5	102	Keryou (2014)
70:30	0.5	92	Keryou (2014)
Control		95	Topcu and Canbaz (2004)
85:15		100	Topcu and Canbaz (2004)
70:30		80	Topcu and Canbaz (2004)
65:45		90	Topcu and Canbaz (2004)
40:60		80	Topcu and Canbaz (2004)
Control	0.55	127	Castro and Brito (2013)
95:5	0.55	131.5	Castro and Brito (2013)
90:10	0.55	132.5	Castro and Brito (2013)
80:20	0.55	134.5	Castro and Brito (2013)
50:50	0.54	80	Ahmad and Aimin (2004)

e: natural gravel

Table 6: Slump of concrete with waste glass as binder, fine and coarse aggregate

C:WG	S : WG	G : WG	W/B Ratio	Slump (mm)	References
Control			0.55	127	Castro and Brito (2013)
100:0	95:5	95:5	0.55	125.5	Castro and Brito (2013)
100:0	90:10	90:10	0.55	122.5	Castro and Brito (2013)
100:0	80:20	80:20	0.57	129.5	Castro and Brito (2013)
100:0	50:50	50:50	0.465	60	Ahmad and Aimin (2004)
100:0	50:50	50:50	0.52	80	Ahmad and Aimin (2004)
100:0	50:50	50:50	0.5	75	Ahmad and Aimin (2004)
Control			0.38	120	Bashar and Ghassan (2008)
80:20	50:50	100:0	0.38	140	Bashar and Ghassan (2008)
80:20	0:100	100:0	0.38	70	Bashar and Ghassan (2008)

ratio of waste glass aggregate increased. Regardless of their color, the slump decreased by 19.6-26.9%, 30.1-34.6% and 38.5-44.3% as the mixing ratios of waste glass aggregates dropped by 30, 50 and 70%, respectively, compared to the plain concrete containing no waste glass. The study reported that additional cement paste attached to the surface of the waste glass with increasing quantity which resulted in less available cement paste necessary for the fluidity of the concrete; besides, the angular grain shapes of glass and larger size than sand particles resulted in less fluidity. However, the color of waste glass aggregates did not severely affect the slump values.

Bashar and Ghassan (2008) replaced natural sand in concrete mixtures with mixed color waste recycled glass (size <5 mm) at levels of 0, 50 and 100%, respectively. There was a reduction in the workability with the inclusion of glass sand. The workability decreased with increasing glass sand content and the reduction in the slump value was 20.83% and 33.33% with the inclusion of 50% and 100% glass sand, respectively. Limbachiya (2009) studied the workability of concrete mixtures containing mixed color beverage waste glass. Natural sand was partially replaced with waste glass at levels of 0, 5, 10, 15, 20, 30 and 50%, respectively by weight. The results showed a reduction in the slump value with increasing waste glass proportions beyond 30%. . Malek *et al*. (2007) partially replaced sand in concrete mixtures with crushed glass at levels of 0, 5, 10, 15 and 20% respectively. The results showed that the workability of the mixtures was not affected by the inclusion of glass sand. As per the research of Castro and Brito (2013), as the fines replacement ratio increases, the loss of workability occurs which means the w/c ratio has to increase to comply with the slump range.

Waste glass as coarse aggregate: Slump values found by several researchers incorporating waste glass as coarse aggregate are presented in Table 5. Keryou (2014) reported that slump decreases with the increase of waste glass percentage. As per his study, this behavior may be attributed to the fact that as the waste glass percentage increases, additional cement paste attaches to the surface of the waste glass, which results in less available cement paste necessary for the fluidity of the concrete. Moreover, the WG aggregate has sharper and more angular grain shapes compared to the rounded shapes of gravel, which results in less fluidity. Srivastava *et al*. (2014) showed that slump value of concrete with waste glass as coarse aggregate decreased with increasing the waste glass content due to the edged and angular grain shapes of the coarse waste glass aggregates. Topcu and Canbaz (2004) studied the replacement of 4 to 16 mm gravel by crushed glass aggregate in ratios from 0% to 60%. While using a high proportion of waste glass, decrease in slump value was observed as much as 0.2% due to the fact that glass has a poor geometry. Castro and Brito (2013) showed that the behavior of the mixes is highly dependent on the size of the aggregates replaced. There is a slight increase in the slump value as that replacement ratio increases for a constant w/c ratio of 0.55.

Waste glass as binder, fine and coarse aggregate: Slump values found by several researchers incorporating waste glass as binder, fine and coarse aggregate are presented in Table 6. Castro and Brito (2013) used waste glass partially as coarse and fine aggregate. The mix of fine and coarse aggregates in the research work has an intermediate behavior, leading to the water/cement ratio increasing from 0.55 to 0.57 for an overall replacement of 20%.

DENSITY OF CONCRETE INCORPORATING WASTE GLASS

Waste glass powder as binder material: Fresh density values found by several researchers incorporating waste glass as binder material are presented in Table 7. As per the studies of Kumarappan (2013), densities of the mixes seem to be similar except the mix with 40% glass powder, which had a slight drop of density. Research work of Khatib *et al*. (2012) was almost similar to Kumarappan (2013) showing no significant change in the values of fresh density. Bashar and Ghassan (2008) observed that wet density of the glass concrete was slightly reduced due to the lower density of PGP

Table 7: Density of concrete with waste glass as binder material

C: Others: WG	Density (kg/m3)	References
Control	2375	Kumarappan (2013)
90:0:10	2375	Kumarappan (2013)
80:0:20	2375	Kumarappan (2013)
70:0:30	2625	Kumarappan (2013)
60:0:40	2125	Kumarappan (2013)
Control	2280	Khatib *et al*. (2012)
90:0:10	2280	Khatib *et al*. (2012)
80:0:20	2280	Khatib *et al*. (2012)
70:0:30	2310	Khatib *et al*. (2012)
60:0:40	2190	Khatib *et al*. (2012)
Control	2440	Bashar and Ghassan (2008)
80:0:20	2410	Bashar and Ghassan (2008)
Control	2299	Nassar and Soroushian (2012)
80:0:20	2209	Nassar and Soroushian (2012)
Control	2208	Nassar and Soroushian (2012)
80:0:20	2118	Nassar and Soroushian (2012)

Table 8: Density of concrete with waste glass as fine aggregate

S: WG	Density	References
100:0	2476.9	Ismail and Hashmi (2009)
90:10	2445.7	Ismail and Hashmi (2009)
85:15	2428.3	Ismail and Hashmi (2009)
80:20	2420.9	Ismail and Hashmi (2009)
100:0	2440	Bashar and Ghassan (2008)
50:50	2430	Bashar and Ghassan (2008)
0:100	2390	Bashar and Ghassan (2008)
Control	2305.6	Malek *et al*. (2007)
95:5	2301	Malek *et al*. (2007)
90:10	2302.2	Malek *et al*. (2007)
85:15	2289.3	Malek *et al*. (2007)
80:20	2286.3	Malek *et al*. (2007)
Control	2365	Castro and Brito (2013)
95:5	2348	Castro and Brito (2013)
90:10	2348	Castro and Brito (2013)
80:20	2339	Castro and Brito (2013)

Table 9: Density of concrete with waste glass as coarse aggregate

G: WG	Density (kg/m3)	References
Control	2400	Keryou (2014)
80:20	2388	Keryou (2014)
75:25	2380	Keryou (2014)
70:30	2372	Keryou (2014)
Control	2340	Topcu and Canbaz (2004)
85:15	2335	Topcu and Canbaz (2004)
70:30	2340	Topcu and Canbaz (2004)
65:45	2330	Topcu and Canbaz (2004)
40:60	2335	Topcu and Canbaz (2004)
Control	2365	Castro and Brito (2013)
95:5	2365	Castro and Brito (2013)
90:10	2337	Castro and Brito (2013)
80:20	2298	Castro and Brito (2013)

compared to normal cement. As per Nassar and Soroushian (2012) Density of the fresh concrete slightly decreased due to the addition of waste glass as partial replacement of cement. The lower specific gravity of waste glass compared to that of cement is the reason in this case.

Waste Glass as Fine Aggregate: Fresh density values found by several researchers incorporating waste glass as coarse aggregate are presented in Table 8. Ismail and Hashmi (2009) stated that decreasing ratios in fresh densities of concrete made of 10, 15 and 20% waste glass are 1.28, 1.96 and 2.26%, respectively. As per this study, the decrease in the fresh density of the waste glass concrete mixes can be attributed to the specific gravity of the waste glass, which is approximately 14.8% lower than that of the sand. As per Bashar and Ghassan (2008), there is no severe difference in fresh density when sand is replaced by 50% or 100% glass. Malek *et al*. (2007) reported no significant impact on density due to addition of glass sand. From the research work of Castro and Brito (2013), it is observed that there is a clear reduction of the fresh density with the incorporation of glass sand. This tendency can be explained by the difference between natural aggregate and glass aggregate in terms of particles density.

Waste glass as coarse aggregate: Fresh density values found by several researchers incorporating waste glass as coarse aggregate are presented in Table 9. From the studies of Keryou (2014) it is visible that the density of concrete with waste glass decreases with increasing

Table 10: Density of concrete with waste glass as binder, fine and coarse aggregate

C:WG	S : WG	G:WG	Density	References
Control			2365	Castro and Brito (2013)
100:0	95:5	95:5	2336	Castro and Brito (2013)
100:0	90:10	90:10	2350	Castro and Brito (2013)
100:0	80:20	80:20	2319	Castro and Brito (2013)
Control			2440	Bashar and Ghassan (2008)
80:20	50:50	100:0	2400	Bashar and Ghassan (2008)
80:20	0:100	100:0	2380	Bashar and Ghassan (2008)

percentages of glass due to the difference between density of glass and natural coarse aggregate. However, the decrease in density is not observed to be significant within the glass percentages used. Topcu and Canbaz (2004) observed a decline as much as 0.3% in density. Such a difference was attributed to the fact that the specific general rock. Castro and Brito (2013) also reported notable decrease in density with coarse aggregate replacement by waste glass.

Waste glass as binder, fine and coarse aggregate: Fresh density values found by several researchers incorporating waste glass as binder, fine and coarse Aggregate are presented in Table 10. Castro and Brito (2013) showed 10% replacement of both coarse and fine aggregate by waste glass provides fresh density of 2350 kg/m^3 whereas the density of control mix is 2365 kg/m^3.

COMPRESSIVE STRENGTH OF CONCRETE INCORPORATING WASTE GLASS

Waste glass powder as binder material: Compressive strength values found by several researchers incorporating waste glass as binder material are presented in Table 11. As per the studies of Vasudevan and Kanapathypillay (2013), concrete with waste glass powder have higher strength at 14 days but once the concrete reaches 28th day, the control mix gives higher value compared to the mix that contains waste glass powder. The optimum percentage of glass powder can be considered to be 20% from this research. Kumarappan (2013) stated that the optimum percentage of glass powder addition is 10. Above 20% glass powder replacement, strength substantially decreases. Khatib *et al*. (2012) also stated that 10% of glass addition can be considered to be optimum. Kou and Xing (2012) proved that replacement of cement by glass powder decreases the early (before 7 days), but increases the later (after 28 days) compressive strength. From the studies of Vandhiyan *et al*. (2013), It is visible that there a reduction in the strength at 15% glass replacement. 10% replacement of cement by glass powder provides maximum compressive strength. It may be attributed to the fact that waste glass when ground to a very fine powder, SiO2 reacts chemically with alkalis in cement and form cementitious product that contribute to the strength development. Another reason may be glass powder effectively filling the voids and giving rise to a dense concrete. Jangid and Saoji (2014) observed that strength increased upto 30% replacement of cement by glass powder compared to that of control mix. Above 20%, strength started to decrease and at 20% replacement compressive strength was at highest peak. As per Jihwan *et al*. (2014), the compressive strengths of concrete with 5-10% waste glass, are higher than those of the control mixture with 20% fly ash, at all ages after casting. Madandoust and Ghavidel (2013) used waste glass and rice husk ash as partial replacement of cement. Based on the 28-day strength results, concrete mix with 10% glass powder and 5% rice husk ash met the strength requirement of 40 MPa. The compressive strength of the control concrete was greater than those of hybrid mix at all ages. This difference declines with age. Like, the compressive strength of the optimum mix at 3 days was 65% of the conventional concrete; which increased to 89% at 28 days and 96% at 90 days. This result shows an indication of pozzolanic reactivity which can also be attributed to the particle sizes of the fines used in this research. Ahmad and Aimin (2004) observed that concrete mixtures containing GLP have lower initial strength values, but with time they develop strength under moist curing conditions and reach the strength of the control mixture. It has been concluded from this study that 30% GLP could be incorporated as cement replacement in concrete without any long-term detrimental effects. Bashar and Ghassan (2008) stated that there was an average reduction in the compressive strength of 16%, when 20% of Cement was replaced by glass powder. This can be a direct result of the change in the nature of the hydration products and C-S-H gel. Shao *et al*. (2000) used glass powder of three sizes which are 150, 75 and 38 micrometer. Glass concretes had lower strengths than the control mix at the ages of 3, 7, 28 and 90 days, except that the strength of the concrete containing 38 micrometer glass exceeded that of control by 8% after 90 days of curing. It was attributed to the fact that the smaller the particle size of the glass, the higher the strength of the glass concrete. Chikhalikar and Tande (2012) stated that 20% replacement of cement by waste glass powder will result in higher strengths than that of control mix. Nassar and Soroushian (2012) experimented with both low and high water/binder ratio. It was found that the 14 day strength of glass concrete is lower compared to that of control mix but the 56 day strength is almost similar to that of control mix.

Table 11: Compressive strength of concrete with waste glass as binder material

C : Others : WG	W/B Ratio	Compressive strength 7 Days	14 Days	28 Days	56 Days	60 Days	90 Days	References
Control		19	26	33				Vasudevan and Kanapathypillay (2013)
90:0:10		19	22	25				Vasudevan and Kanapathypillay (2013)
85:0:15		20	23	29				Vasudevan and Kanapathypillay (2013)
80:0:20		20	29	32				Vasudevan and Kanapathypillay (2013)
Control	0.5			30				Kumarappan (2013)
90:0:10				36				Kumarappan (2013)
80:0:20				24				Kumarappan (2013)
70:0:30				21.5				Kumarappan (2013)
60:0:40				16				Kumarappan (2013)
Control	0.5			29.5				Khatib *et al*. (2012)
90:0:10				32				Khatib *et al*. (2012)
80:0:20				21				Khatib *et al*. (2012)
70:0:30				19.5				Khatib *et al*. (2012)
60:0:40				12				Khatib *et al*. (2012)
Control	0.15			139				Kou and Xing (2012)
75:10:15				148				Kou and Xing (2012)
60:10:30				151				Kou and Xing (2012)
Control	0.45	23	28.4	33.2				Vandhiyan *et al*. (2013)
95:0:5		26.8	31.61	34.79				Vandhiyan *et al*. (2013)
90:0:10		30.3	33.03	36.18				Vandhiyan *et al*. (2013)
85:0:15		24.53	27.25	32.04				Vandhiyan *et al*. (2013)
Control	0.48			27.01		27.29		Jangid and Saoji (2014)
95:0:5				28.62		28.89		Jangid and Saoji (2014)
90:0:10				29.81		30.09		Jangid and Saoji (2014)
85:0:15				31.66		31.9		Jangid and Saoji (2014)
80:0:20				33.42		33.89		Jangid and Saoji (2014)
75:0:25				30.51		30.81		Jangid and Saoji (2014)
70:0:30				24.2		24.41		Jangid and Saoji (2014)
65:0:35				24.21		22.76		Jangid and Saoji (2014)
60:0:40				19.01		19.26		Jangid and Saoji (2014)
Control	0.45	19.5	24	27	29.2		30	Jihwan *et al*. (2014)
80:10:10	0.45	22	26	30	32		32.2	Jihwan *et al*. (2014)
80:10:10	0.4	26.5	27.5	33	37		37.5	Jihwan *et al*. (2014)
95:0:5	0.45	26.5	32	33	36		36.5	Jihwan *et al*. (2014)
90:0:10	0.45	24.5	27.5	30	32		32.5	Jihwan *et al*. (2014)
Control	0.51	31	40	44			56	Madandoust and Ghavidel (2013)
90:5:5				38				Madandoust and Ghavidel (2013)
85:10:5				34				Madandoust and Ghavidel (2013)
85:5:10		23.5	30.5	40			55	Madandoust and Ghavidel (2013)
80:10:10				31				Madandoust and Ghavidel (2013)
80:15:10				28.5				Madandoust and Ghavidel (2013)
80:5:15				32.5				Madandoust and Ghavidel (2013)
Control				53.5	57		59	Ahmad and Aimin (2004)
90: 0: 10				52	58		64	Ahmad and Aimin (2004)
80: 0: 20				49	56		59	Ahmad and Aimin (2004)
70: 0: 30				44	52		57	Ahmad and Aimin (2004)
Control	0.38			77				Bashar and Ghassan (2008)
80:0:20				63.5				Bashar and Ghassan (2008)
Control	0.75	16.5		21			23	Shao *et al*. (2000)
70:0:30		12		15			19.8	Shao *et al*. (2000)
70:0:30		12.5		17.8			21	Shao *et al*. (2000)
70:0:30		14		20			25.2	Shao *et al*. (2000)
Control	0.45			36.12				Chikhalikar and Tande (2012)
90:0:10				37.54				Chikhalikar and Tande (2012)
80:0:20				41.91				Chikhalikar and Tande (2012)
70:0:30				39.53				Chikhalikar and Tande (2012)
60:0:40				33.56				Chikhalikar and Tande (2012)
Control	0.47		41		53			Nassar and Soroushian (2012)
80:0:20			32		51			Nassar and Soroushian (2012)
Control	0.62		34.7		42.8			Nassar and Soroushian (2012)
80:0:20			27		42			Nassar and Soroushian (2012)

Waste Glass as Fine Aggregate: Compressive strength values found by several researchers incorporating Waste Glass as Fine Aggregate are presented in Table 12. Wang and Huang (2010) reported compressive strengths of the concretes containing waste glass decreased with an increase in glass content. The concrete containing 20% waste glass resulted in the highest strength properties. Compressive strength

Table 12: Compressive strength of concrete with waste glass as fine aggregate

S : WG	W/B Ratio	3 Days	7 Days	14 Days	28 Days	56 Days	90 Days	References
100:0	0.28		42		66		75.5	Wang and Huang (2010)
90:10	0.28		46		63		70	Wang and Huang (2010)
80:20	0.28		49		60.5		77	Wang and Huang (2010)
70:30	0.28		43		65		76.5	Wang and Huang (2010)
100:0	0.53	26.9	31.5	43.8	44			Ismail and Hashmi (2009)
90:10	0.53	29.1	34.6	39.1	40.3			Ismail and Hashmi (2009)
85:15	0.53	28.9	32	38.3	42			Ismail and Hashmi (2009)
80:20	0.53	27.6	31.7	38	45.9			Ismail and Hashmi (2009)
Control	0.5		25		36		41	Park *et al*. (2004) emerland green
70:30	0.5		25.5		36		40.5	Park *et al*. (2004) emerland green
50:50	0.5		23		33		38	Park *et al*. (2004) emerland green
30:70	0.5		21.5		30.8		36	Park *et al*. (2004) emerland green
100:0	0.38				77			Bashar and Ghassan (2008)
50:50	0.38				73			Bashar and Ghassan (2008)
0:100	0.38				74.5			Bashar and Ghassan (2008)
Control	0.52				49			Limbachiya (2009)
95:5	0.52				49			Limbachiya (2009)
90:10	0.52				50			Limbachiya (2009)
85:15	0.52				49			Limbachiya (2009)
80:20	0.52				48			Limbachiya (2009)
70:30	0.52				45.5			Limbachiya (2009)
50:50	0.52				43			Limbachiya (2009)
Control	0.56				32			Malek *et al*. (2007)
95:5	0.56				35			Malek *et al*. (2007)
90:10	0.56				37.8			Malek *et al*. (2007)
85:15	0.56				40.5			Malek *et al*. (2007)
80:20	0.56				42.5			Malek *et al*. (2007)
Control	0.5		14.66		30.33			Gautam *et al*. (2012)
90:10	0.5		21.66		31.33			Gautam *et al*. (2012)
80:20	0.5		16.66		31			Gautam *et al*. (2012)
70:30	0.5		16.33		29.66			Gautam *et al*. (2012)
60:40	0.5		16.33		29.33			Gautam *et al*. (2012)
50:50	0.5		20.33		24.33			Gautam *et al*. (2012)

increased at 7 days and 28 days. At 90 days, with a glass replacement of 30%, the compressive strength reached 98.4% of the control mix's compressive strength; the smooth surface of the glass sand allowed more cement paste to participate in adhering the glass to the cement mortar, which enhanced the compressive strength. As per Ismail and Hashmi (2009), the best 28-day compressive strength value of 45.9 MPa was obtained from the concrete mix made of 20% waste glass fine aggregate, which represents an increase in the compressive strength of up to 4.23% as compared to the control mix. Park *et al*. (2004) stated that with mixing ratios of 30, 50 and 70%, respectively there is a reduction in compressive strength, each showing 99.4, 90.2 and 86.4%, compressive strength of the plain concrete, respectively. This inclination may be due to the decrease in adhesive strength between the surface of the waste glass aggregates and the cement paste. The concrete containing waste glass aggregates of 30% gave the highest strength properties. From the studies of Bashar and Ghassan (2008) it can be concluded that there is no clear trend that governs the variation in the compressive strength of concrete with the presence of waste glass sand. Limbachiya (2009) reported that sand replacement by glass up to 20% has no influence on the compressive strength of concrete, but thereafter there was a gradual reduction in strength with increase in glass content. Malek *et al*. (2007) stated that compressive strength is higher than that of normal concrete for up to 20% glass aggregate substitution. This is due to the surface texture and strength of the glass particles compared to that of sand. Castro and Brito (2013) reported that strength of concrete decreases with increasing glass incorporation. This is caused by the weak bond between glass and the cement paste and the higher w/c ratio of the mixes with fine glass aggregate. As per the research of Gautam *et al*. (2012), while using Waste Glass as Fine Aggregate replacement, 28 day strength is found to increase up to 20% replacement level. Decrease in strength is observed at 30 to 40% replacement of waste glass with fine aggregate. The optimum replacement level of Waste Glass as Fine Aggregate is found to be 10%.

Waste glass as coarse aggregate: Compressive strength values found by several researchers incorporating waste glass as coarse aggregate are presented in Table 13. Keryou (2014) reported improved compressive strength of the glass mixed concrete at both ages (7 and 28 days). The maximum strength was reported at 25% replacemt of natural coarse aggregate, where the increases in compressive strength at 7 and 28 days reached 20.5 and 30%, respectively. This can be explained by the fact that the particle shape of the crushed waste glass aggregates was more edged and angular compared to the rounded

Table 13: Compressive strength of concrete with waste glass as coarse aggregate

G : WG	W/B Ratio	7 Days	14 Days	28 Days	Compressive Strength in comparison with reference mix (%)	References
Control	0.5	27.2		30.3		Keryou (2014)
80:20	0.5	30		35.5		Keryou (2014)
75:25	0.5	32.8		39.4		Keryou (2014)
70:30	0.5	26.5		34.4		Keryou (2014)
Control	0.5	13.66		29.67		Srivastava *et al*. (2014)
90:10	0.5	15.67		31		Srivastava *et al*. (2014)
80:20	0.5	14.11		29.67		Srivastava *et al*. (2014)
70:30	0.5	15.33		25.33		Srivastava *et al*. (2014)
60:40	0.5	14.67		27.33		Srivastava *et al*. (2014)
50:50	0.5	15.67		29.67		Srivastava *et al*. (2014)
Control	0.54			23.5		Topcu and Canbaz (2004)
85:15	0.54			21.67		Topcu and Canbaz (2004)
70:30	0.54			20.02		Topcu and Canbaz (2004)
65:45	0.54			16.12		Topcu and Canbaz (2004)
40:60	0.54			12.04		Topcu and Canbaz (2004)
Control	0.55				1	Castro and Brito (2013)
95:5	0.55				1	Castro and Brito (2013)
90:10	0.55				0.978	Castro and Brito (2013)
80:20	0.55				0.97	Castro and Brito (2013)
50:50	0.54	18.5		28.1		Ahmad and Aimin (2004)

Table 14: Compressive strength of concrete with waste glass as binder, fine and coarse aggregate

C:WG	S:WG	G:WG	W/B Ratio	7 days	28 days	Compressive Strength in comparison with reference mix (%)	References
Control			0.55			1	Castro and Brito (2013)
	95:5	95:5	0.55			0.94	Castro and Brito (2013)
	90:10	90:10	0.55			0.91	Castro and Brito (2013)
	80:20	80:20	0.57			0.78	Castro and Brito (2013)
	50:50	50:50	0.465	28.6	39.9		Ahmad and Aimin (2004)
	50:50	50:50	0.52	25.3	35		Ahmad and Aimin (2004)
	50:50	50:50	0.5	19.5	31.2		Ahmad and Aimin (2004)
Control			0.38		77		Bashar and Ghassan (2008)
80:20	50:50	100:0	0.38		63		Bashar and Ghassan (2008)
80:20	0:100	100:0	0.38		63		Bashar and Ghassan (2008)

shape of the natural coarse aggregates, resulting in better interlocking effect and higher friction forces inside the concrete mix. As per Srivastava *et al*. (2014), the optimum replacement level of waste glass as coarse aggregate is 10%. While using waste glass partially as coarse aggregate, the 28 days strength is found to marginally increase up to 20% replacement level. Marginal decrease in strength is observed at 30 to 40% replacement level of waste glass. Topcu and Canbaz (2004) stated that compressive strength was observed to decrease, as the proportion of glass in concrete increased. In the case of 15% addition of glass, there was a decrease of 8% in compressive strength, while there was a decrease of 15% in the compressive strength of concrete with 30% of waste glass. The high brittleness of waste glass leading to cracks was determined to lead to incomplete adhesion between the glass and cement paste inter phase. Castro and Brito (2013) reported 3% lower compressive strength with respect to the control mix.

Waste glass as binder, fine and coarse aggregate: Compressive strength values found by several researchers incorporating waste glass as binder, fine and coarse aggregate are presented in Table 14. As per Castro and Brito (2013), when waste glass is used partially as both fine and coarse aggregate, 22% decline in compressive strength is observed compared to that of control mix. Bashar and Ghassan (2008) used waste glass as both binder and fine aggregate. During the study binder replacement was kept constant at 20% with a varying percentage of fine glass aggregate, which is 50% and 100%. A decline of around 18% in compressive strength is observed compared to that of control mix.

CONCLUDING REMARKS

This literature review deals with the effect of using waste glass on fresh properties and compressive strength of concrete. Depending on the size, angular shape and surface area of the glass powder to be used as a substitute of binder material, around 20% replacement is allowable for better workability of concrete. It was also found that around 10-20% replacement of cement by waste glass powder will result in higher strengths than that of control mix due to the high pozzolanic property of glass powder. When ground to a very fine powder, SiO_2 reacts chemically with alkalis in cement and forms cementitious product that contributes to the strength development. In cases of using waste glass as partial replacement of fine or coarse aggregate, the optimum percentage was found to be 10-20% in terms of workability and compressive strength. Declining slump tendency was noted which may be attributed to the fact that additional cement paste attaches to the surface of the waste glass with increasing quantity which resulted in less available cement paste necessary for the fluidity of the concrete; besides, the angular shapes of glass resulted in less fluidity.

Depending on the size and shape of waste glass, it may be concluded that, it is possible to achieve workable concrete of desired compressive strength with 10-20% replacement of cement or fine aggregate or coarse aggregate by waste glass. The proper use of waste glass in construction industry could develop to build a healthy and sustainable environment. It will also provide a path towards cost effective concrete production.

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REFERENCES

Ahmad, S., 2002. Value-added utilization of waste glass in concrete. Proceeding of the IABSE Symposium, Melbourne.

Ahmad, S. and X. Aimin, 2004. Value-added utilization of waste glass in concrete. Cement Concrete Res., 34: 81-89.

Bashar, T. and N. Ghassan, 2008. Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. Constr. Build. Mater., 22: 713-720.

Caijun, S., 2009. Corrosion of glasses and expansion mechanism of concrete containing waste glasses as aggregates. J. Mater. Civil Eng., 21(10): 529-534.

Castro, S.D. and J.D. Brito, 2013. Evaluation of the durability of concrete made with crushed glass aggregates. J. Clean. Prod., 41: 7-14.

Chai, L.T., P.C. Sun and W.H. Wing, 2013. Management and recycling of waste glass in concrete products: Current situations in Hong Kong. Resour. Conserv. Recy., 70: 25-31.

Chikhalikar, S.M. and S.N. Tande, 2012. An experimental investigation on characteristics properties of fibre reinforced concrete containing waste glass powder as pozzolona. Proceeding of the 37th Conference on Our World in Concrete and Structures. Singapore.

Gautam, S.P., V. Srivastava and V.C. Agarwal, 2012. Use of glass wastes as fine aggregate in Concrete. J. Acad. Ind. Res., 1(6): 320-322.

IEA, 2007. Tracking Industrial Energy Efficiency and CO2 Emissions. OECD/IEA, pp: 1-321.

Ismail, Z.Z. and E.A.A. Hashmi, 2009. Recycling of waste glass as a partial replacement for fine aggregate in concrete. Waste Manage., 29: 655-659.

Jangid, J.B. and A.C. Saoji, 2014. Experimental investigation of waste glass powder as the partial replacement of cement in concrete production. Proceeding of the International Conference on Advances in Engineering and Technology (ICAET-2014), pp: 55-60.

Jevtic, D., D. Zakic and A. Savic, 2012. Achieving sustainability of concrete by recycling of solid waste materials. Mech. Test. Diagn., 1(2): 22-39.

Jihwan, K., M.J.H. Moon, J.W. Shim, J. Sim, H.G. Lee and G. Zi, 2014. Durability properties of a concrete with waste glass sludge exposed to freeze-and-thaw condition and de-icing salt. Constr. Build. Mater., 66: 398-402.

Karim, M.R., M.M. Hossain, M.N.N. Khan, M.F.M. Zain, M. Jamil and F.C. Lai, 2014. On the utilization of pozzolanic wastes as an alternative resource of cement. Materials, 7: 7809-7827.

Keryou, A.B., 2014. Effect of using windows waste glass as coarse aggregate on some properties of concrete. Eng. Tech. J., 32(A): 1519-1529.

Khan, M.N.N., M. Jamil, M.R. Karim and M.F.M. Zain, 2014. Strength and durability of mortar and concrete containing rice husk ash: A review. World Appl. Sci. J., 32(5): 752-765.

Khan, M.N.N., M. Jamil, M.R. Karim, M.F.M. Zain and A.B.M.A. Kaish, 2015. Utilization of rice husk ash for sustainable construction: A review. Res. J. Appl. Sci. Eng. Technol., 9(12): 1119-1127.

Khatib, J.M., H.S. Sohl and N. Chileshe, 2012. Glass powder utilization in concrete production. Eur. J. Appl. Sci., 4(4): 173-176.

Kou, S.C. and F. Xing, 2012. The effect of recycled glass powder and reject fly ash on the mechanical properties of fiber-reinforced ultrahigh performance concrete. Adv. Mater. Sci. Eng., 2012: 1-8.

Kumarappan, N., 2013. Partial replacement cement in concrete using waste glass. Int. J. Eng. Res. Technol., 2(10): 1880-1883.

Ledererova, M. and K. Grunner, 2006. Optimization of the technology for recycling concrete materials. Slovak J. Civ. Eng., 4: 29-40.

Limbachiya, M.C., 2009. Bulk engineering and durability properties of washed glass sand concrete. Constr. Build. Mater., 23: 1078-1083.

Madandoust, R. and R. Ghavidel, 2013. Mechanical properties of concrete containing waste glass powder and rice husk ash. Biosyst. Eng., 116: 113-119.

Malek, B., M. Iqbal and A. Ibrahim, 2007. Use of selected waste materials in concrete mixes. Waste Manage., 27: 1870-1876.

Medina, C., M.I.S. Rojas and M. Frías, 2013. Freeze-thaw durability of recycled concrete containing ceramic aggregate. J. Clean. Prod., 40(2013): 151-160.

Mehta, P.K. and P.J.M. Monteiro, 2006. Concrete: Microstructure, Properties and Materials. 3rd Edn., McGraw-Hill, New York.

Meyer, C., 2009. The greening of the concrete industry. Cement Concrete Comp., 31: 601-605.

Nassar, R. and P. Soroushian, 2012. Strength and durability of recycled aggregate concrete containing milled glass as partial replacement for cement. Constr. Build. Mater., 29: 368-377.

Park, S.B., B.C. Lee and J.H. Kim, 2004. Studies on mechanical properties of concrete containing waste glass aggregate. Cement Concrete Res., 34: 2181-2189.

Roskovic, R. and D. Bjegovic, 2005. Role of mineral additions in reducing CO2 emission. Cement Concrete Res., 35: 974-978.

Serniabat, T.S., M.N.N. Khan and M.F.M. Zain, 2014. Use of waste glass as coarse aggregate in concrete: A possibility towards sustainable building construction. Int. J. Civil Environ. Struct. Constr. Architect. Eng., 8(10): 1027-1030.

Shao, Y., T. Lefort, S. Moras and D. Rodriguez, 2000. Studies on concrete containing ground waste glass. Cement Concrete Res., 30(1): 91-100.

Siddique, R., 2008. Waste Materials and By-products in Concrete. Springer-Verlag, Berlin.

Srivastava, V., S.P. Gautam, V.C. Agarwal and P.K. Mehta, 2014. Glass wastes as coarse aggregate in concrete. J. Environ. Nanotechnol., 3: 67-71.

Topcu, I.B. and M. Canbaz, 2004. Properties of concrete containing waste glass. Cement Concrete Res., 34(2004): 267-274.

US EPA, 2012. Glass, Common Wastes and Materials. Wastes Resources Conservation-common Wastes and Materials. Retrieved from: http://www.epa.gov/osw/conserve/materials/glass.Htm#content.

User Guidelines for Waste and Byproduct Materials in Pavement Construction, 1997. US Department of Transportation Federal Highway Administration. Publication No. FHWA-RD-97-148.

Vandhiyan, R., K. Ramkumar and R. Ramya, 2013. Experimental study on replacement of cement by glass powder. Int. J. Eng. Res. Technol., 2(May 5): 234-238.

Vasudevan, G. and S.G. Kanapathypillay, 2013. Performance of using waste glass powder in concrete as replacement of cement. Am. J. Eng. Res., 2(12): 175-181.

Wang, H.Y. and W.L. Huang, 2010. Durability of self-consolidating concrete using waste LCD glass. Constr. Build. Mater., 24: 1008-1013.

Zain, M.F.M., M.N. Islam, F. Mahmud and M. Jamil, 2011. Production of rice husk ash for use in concrete as a supplementary cementitious material. Constr. Build. Mater., 25(2): 798-805.

Zhang, M.H. and M.V. Mohan, 1996. High-performance concrete incorporating rice husk ash as a supplementary cementing material. ACI Mater. J., 93(6): 629-636.