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Some Durability Properties of Self-Compacting Concretes Containing Recycled Waste Glass as a Replacement of Cement: A Review

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Abstract: *The maintenance and construction of buildings consume huge amounts of cement leading to increase the pollution and cost. Using of recycled materials such as recycled waste glass (RWG), instead of fundamental materials decreases the cost of waste disposable which helps easing landfill pressures and saving large amount of natural sources as raw material. Since RWG have approximately the same chemical compounds of cement that made it an excellent material using instead of cement partially but, one problem faced the researcher is the Alkali-Silica Reaction (ASR) which is a chemical interaction between numerous amount of silica in glass and the alkali in concretes and the results of this reaction precipitate in pore solution. The objective of this review is to focus on some durability research requirement that will assist get this type of materials nearer to international employ.*

Keywords: Durability, Glass powder, Recycled waste glass, Self-compacting concrete.

بعض خصائص الديمومة للخرسانة ذاتية الرص الحاوية على نفايات الزجاج المعاد تدويرها كنسبة مستبدلة من الإسمنت - بحث مراجعة

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المستخلص
ان الهدف من وراء هذه المراجعة هو تلخيص خصائص انكماش الجفاف، الامتصاص، النفاذية للخرسانة ذاتية الرص باستخدام مسحوق مخلفات الزجاج المعاد تدويره RWG كبديل جزئي للاسمنت.
تستهلك عملية صيانة المباني وتشييدها كميات هائلة من الأسمنت مما يؤدي إلى زيادة التلوث والتكلفة . ان استخدام المواد المعاد تدويرها مثل مخلفات الزجاج المعاد تدويره (RWG) ، بدلاً من المواد الأساسية يقلل من تكلفة النفايات التي يمكن التخلص منها مما يساعد على تخفيف الضغط على مدافن النفايات وتوفير كمية كبيرة من المصادر الطبيعية كمواد خام . نظرًا لأن RWG تحتوي تقريبًا على نفس المركبات الكيميائية للأسمنت جعلت منها مادة ممتازة للاستخدام بدلاً من الأسمنت بصورة جزئيَّة، لكن إحدى المشكلات التي واجهت الباحث هي تفاعل القلويات الموجودة في الاسمنت والسيليكا (ASR) وهو تفاعل كيميائي بين السيليكا الموجودة في الزجاج و القلويات الموجودة في الخرسانة وترسب نتائج هذا التفاعل في محلول المسام . ان الهدف من هذه المراجعة هو التركيز على بعض متطلبات الديمومة للخرسانة و التي ستساعد في جعل هذا النوع من المواد أقرب إلى الاستخدام العالمي.
من خلال مراجعة البحوث تبين انه من الممكن استخدام مسحوق نفايات الزجاج المعاد تدويره كأستبدال جزئي عن الاسمنت في الخرسانة ذاتية الرص يحسن بعض الخصائص الخرسانية و الى نسبة 30%، كما انه اضافة 5% من رماد الفحم مع نسبة 30% استبدال للسمنت يحسن من الخصائص الخرسانية وذلك لان طحن الزجاج بمقاس اقل من 100µm يزيد من الفعالية البوزولانية للزجاج.
الكلمات المفتاحية: الديمومة، مسحوق الزجاج ، نفايات الزجاج المعاد تدويره، الخرسانة ذاتية الرص

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1. Introduction

Portland cement is the major component of concrete. However, manufacture of cement is not favorable for environment because, manufacture of one ton of cement result about 0.7 ton of CO_2. This CO_2 is the main causes of global warming. Therefore, using alternative binder such as fly ash, silica fume, slag, and waste glass should be used as a partial or complete replacement of Portland cement in concrete [1].

Glass is a rare inactive and perfect material for reusing which could be reused numerous times with no changes in its chemical characteristics. A 7% of solid waste which is about 200 million tons is glass in all over the world according to United Nations. Since the glass is not biodegradable, the waste glass goes to landfill this is the current solution until now [2].

Since glass amorphous and consist of large quantities of calcium and silicon, so theoretically, it is pozzolanic or cementitious material if it is grounded finely. For that reason and due to cement is more expensive than glass, thus glass can be used as Portland cement replacement in concretes for economics and environmental advantages [3].

The Concrete Society and Building Research Establishment (BRE) defined Self-Compacting Concrete (SCC) as "The capacity of concrete to flux due to its own weighing and wholly top up the mould, while preserving uniformity even in the existence of heavy reinforced, and then compacting with no need for vibrating compaction".

The durability of concretes construction is exceedingly related to the permeability of the superficies coat, the property that should minimize the entrance of matter which can lead to or expansibility prospective mischievous behaviors (Carbon dioxide, acids, chlorides, oxygen, sulphates, alkalis, water). From practically views, durability counts on the substances which were chosen, concrete synthesis, in addition to the grade of oversight through placing, compaction, finishing and curing [4].

Insufficiency of consolidation of the superficies coat, since the vibration onerousness in thin distances between the moulds and the steel reinforcing rods or other obstacles (e.g. post-tensioning ducts) has been observed as a mystery agent of tacky durability behavior of a steel reinforced concrete construction bared to offensive climates. To beat that was one of the major causes for the original spread of SCC in Japan [5].

Self-compacting concrete with the correct ratios will be free from these ones flaws and the outcome is a material of consistently less and regular permeability, led to few soft points for harmful behavior of the environment and, so increase the durability. According to permeability the compare between SCC and normal vibrated concrete will count on the choosing of materials and the effective water cement or water binder ratio [6].

Therefore, the targets of this review to brief durability shrinkage, absorption, and permeability characteristics of self-compacting concrete with RWG as cement powder.

2. Literature Review

The durability properties of concrete depend mainly on the fresh and mechanical properties of the concrete at its early ages, and since there is a lot of research that focused on the fresh and mechanical properties of self-compacting concrete that contains recycled waste glass as cement binder, so some durability properties of self-compaction concrete containing recycled waste glass as cement binder will be focused on it in this part of research [2].

In practice, two factors are important: volumetric stability and long term durability. These two factors are connected [2].

2.1. *Drying Shrinkage*

The effect of RWG as cement in self- compacting concrete has been studied by Shi et al.[7] and Shi and Wu [8] reported that the drying shrinkage of concretes consisting fly ash was less than that with glass powder, also they said that when glass fineness increase the drying shrinkage decrease. Regarding with that, Shayan and Xu [9] also explained that drying shrinkage of concrete

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containing 20-30% powder of glass with 10μm was more than that of control mix, and when the glass powder increased the drying shrinkage increase as shown in Figure 1. These results confirmed with the consistent of Jawed and Skalny [10] when they explained the effect of alkali on shrinkage. While, Dumitru et al. [11] used 7.5%, 15% and 25% of powder glass as substitution of cement. The compressive of concretes consist of glass powder as cementitious material was less than that of reference mix and drying shrinkage was higher with concrete containing glass powder. However all mixes were meet the design requirements. This conclusion confirms with Shi and Wu [8] which produced self-compacting lightweight concrete by using fly ash and glass powder to increase resistance to segregation and filing ability. They found that glass powder increases the shrinkage.

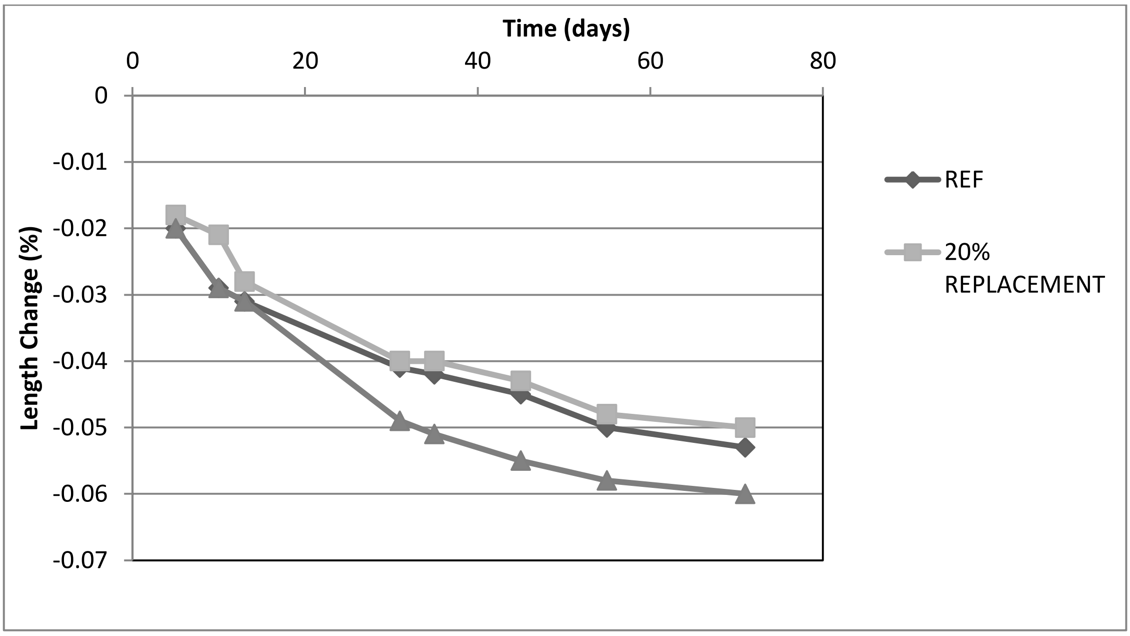

Figure 1: Drying Shrinkage of Concrete Consists of Different Replacement of RWG as Cement [9].

2.2. *Absorption*

Using of RWG in SCC as cement powder has been discussed by Nassar and Soroushian [12] mixed a grained waste glass with 13 microns particle size as a fractional surrogate of cement and aggregate made from reused concrete. These replacements produced an improved in sorptivity. While, Schwarz et al. [13] said that the durability of concrete can be enhanced by using fine glass powder. They claimed that using 10% substitution of cement by glass powder was the greatest substitution according to compressive strength and hydration test. They found that due to low water absorption of glass powder lead to improve the cement hydration especially at short ages. The variance of compressive strengths at 90 days of concrete consisting of 10% glass powder and concrete with 10% fly ash with control mixes was only 5%.

Nwaubani and Poutos [14] examined the concrete mortar using grounded green glass with fineness of 300μm as 5%, 20% and 30% cement replacement. The results indicated that the flow tables were decreased with increases the amount of glass amount. Also, increasing the amount of glass leads to increase the water absorption.

Liu [15] tested the fresh and hardened characteristics of mortar made of green glass as a fractional substitution level by volume of cement and /or fine natural aggregate. It was concluded that the W/P should be increased and reduced the dosage of superplasticizer when addition of ground glass. Also, the results showed that there was a very little increment in the sorptivity of SCCs with glass increases and the sorptivity at 90 days is just 50% of that at 7 days.

Du and Tan [16] investigated about the depth of water penetrate in concrete when glass powder used as partial replacement of cement. They observed low water penetration up to 60% replacement

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of RWG powder compared to reference mix as shown in Figure 2. Same conclusion was reported by Parghi and Alam [17] but, with cement replacement up to 30% Figure 3.

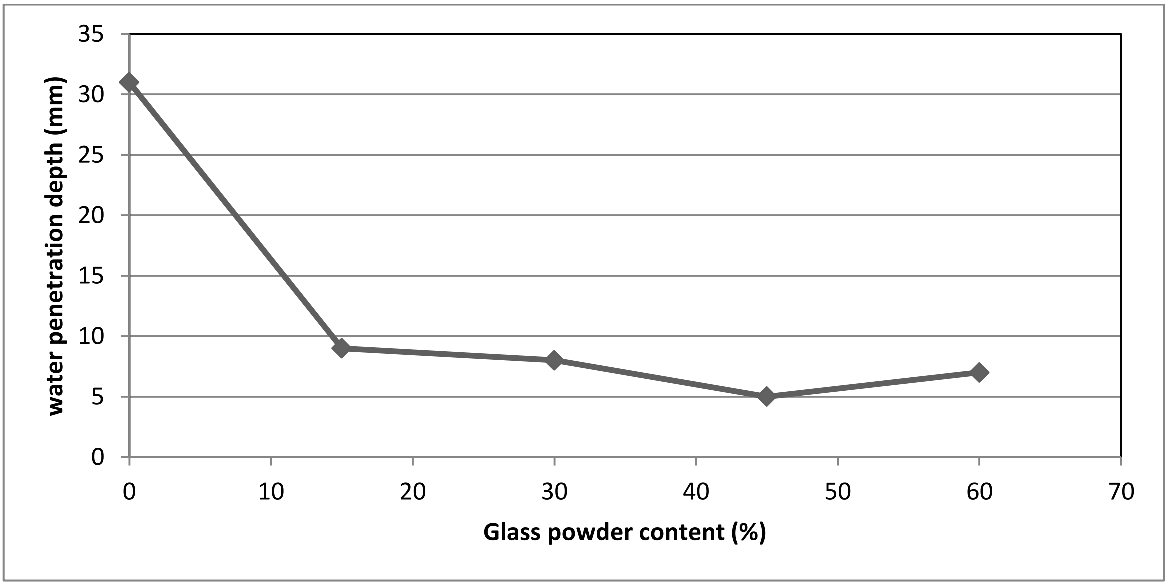

Figure 2:The Relation Between Depth of Water Penetrate and Different Amounts of Glass Powder [16]

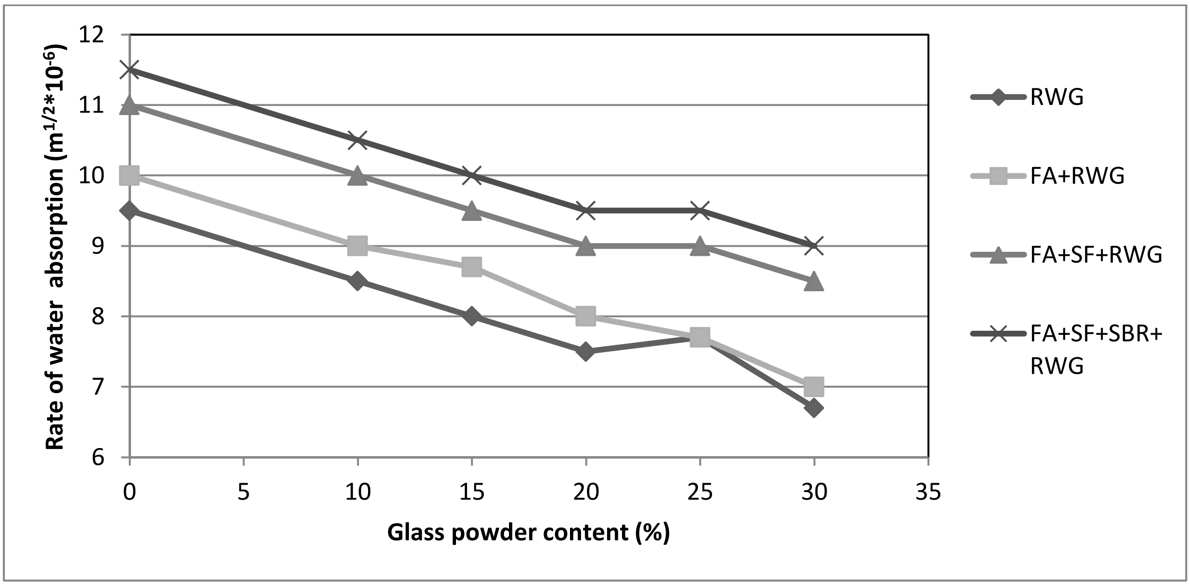

Figure 3: The Relation Between Glass Powder Content and Rate of Water Absorption After 28 Days Curing [17]

3. Permeability

Many researches were done to study the penetration of SCC with RWG as cement summarizes the following articles. Nassar and Soroushian [12] concluded in their study that using 13 microns particle size as a fractional surrogate of cement and aggregate made from reused concrete reduces chlorides permeability.

Tuncan et al. [18] recommended with 30% fly ash and15% glass replacement concrete mixtures, since that mixture gave the best result according to indirect tensile stress, the coefficient of capillary permeability and compressive strength.

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However, Shi and Wu [8] produced self-compacting lightweight concrete by using fly ash and glass powder to increase resistance to segregation and filing ability. They found that glass powder reduces the setting time and increases strength and chloride resistance of concrete. They concluded that finer glass powder lead to increase pozzolanic activity. While, the results of Schwarz et al. [13] showed that replacement the cement by 10% glass powder enhance the rapid chloride permeability, alkali–silica reactivity and wetness moving properties.

Ozkan and Yuksel [19] exacted the durability characteristics of cement mortars with reuse glass as pozzolan, at replace the cement by 10%, 30% and 50% glass powder. Resistance to sulfates and sodium chlorides were examined by matching the compressive strength of normal cement mortar samples and with these subjected to chemicals, they approved that the substitution of cement by glass powder improved durability of mortars subjected to sulfate attack. The results appeared that the reduction in strengths at 30% replacement level was accepted and the durability properties were also good.

Corinaldesi et al. [20]; Chen et al. [21]; Shayan and Xu [9]; Shi and Wu [8] and Shi et al. [7] found that the durability characteristics such as chlorides penetration test was enhanced after addition between 20-30% powder of glass compared to fly ash concrete due to enhance the pore structure of concrete and pozzolanic reactivity.

Finally, Ana Mafalda Matos et al. [22] replaced 50% of the waste glass powder instead of cement and limestone in SCC. They concluded that the Coefficients of chloride diffusion for control samples were decreased from $9.58\text{x}10^{-12}$ to $3.72\ \text{x}10^{-12}\ \text{cm}^2/\text{s}$ for SCC with waste glass powder. Also, the oxygen permeability decreased when the waste glass powder uses as filler. Sales et al., [23] showed that Oxygen permeability found to be decreased with the glass powder contents increase in concrete as shown in Figure 4. This behavior may be due to the structure and chemical compositions of silica, since there is greater pozzolanic reaction. This reaction decreased the porosity of concrete and its permeability. Note that the time for curing specimens in Figure 4 in water were 60 days, which may provide enough moisture for hydration of binders and enhanced permeability of concrete.

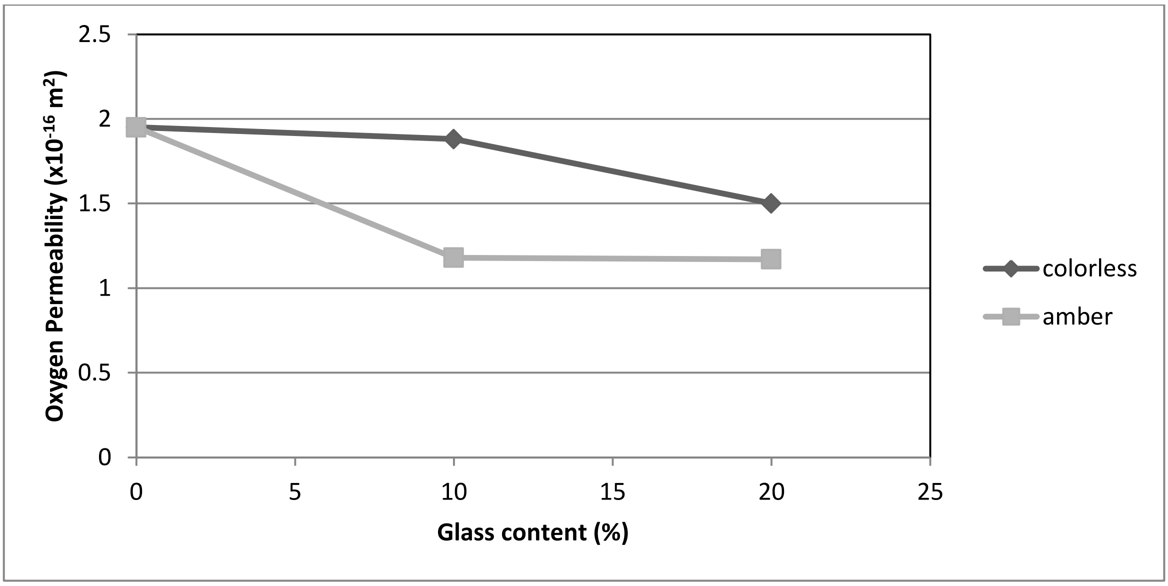

Figure 4: Oxygen Permeability of Concrete with Different Percentages of Glass Powder Used as Binder [23]

4. Other Durability Characteristics

Using RWG powder has also some other effects on the SCC for example, Nassar and Soroushian [12] showed that it increase the resistance to failure because freeze-thaw cycles. This improvement was because of improve the pore structure with glass by supporting to block the

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cavities through transformation the calcium silicate which were exist in old cement mortar of aggregate to calcium silicate hydrate. The results of this transformation were less permeable microstructure and denser which led to an improvement in long life strengths. The growth of strength after 56 curing days gives vicarious proof of pozzolanic activity of waste glass. However, Shi and Wu [8] concluded that finer glass powder lead to increase pozzolanic activity. While, Schwarz et al. [13] said that the alkali–silica reactivity and wetness moving properties of concrete can be enhanced by using fine glass powder.

Corinaldesi et al. [20]; Chen et al. [21]; Shayan and Xu [9]; Shi and Wu [8] and Shi et al. [7] found that the freezing/thawing aggression and sulfate resistance of concrete were enhanced after addition between 20-30% powder of glass compared to fly ash concrete due to enhance the pore structure of concrete and pozzolanic reactivity.

Narayanan Neithalath [24] explained that using of coarse glass powder as cement replacement is useful in pastes with low water/cement ratio where a part of cement still un-hydrated. The results showed that the heat of hydration per unit mass of cement increased with increasing the amount of glass. However, regardless of glass powder content, the heat of hydration reduces because of the control of mitigation (decrease of cement content which lead to decrease the hydration outputs) effect.

All the types of glasses which used in above articles were crushed into different sizes depending on the type of crusher so, the pozolanic activity different depending on the size of glass particles and the color of glasses which were used. Table 1 summarized the chemical analysis of glasses which were used in this article.

Table 1: Chemical Composition of Waste Glass Samples, and Fly Ash [7-24]

Compounds %	Clear glass powder	Color glass powder	Fly ash
SiO_2	68.1	68.7-71.91	59.2
Al_2O_3	0.9	1.0-2.24	25.6
Fe_2O_3	0.6	0.01-0.9	2.9
CaO	14.5	12-13.5	1.1
MgO	1.8	1.8-2.1	0.3
K_2O	0.8	1.0	0.9
Na_2O	12.2	13.3	0.2
SO_3	0.4	0.1-0.2	0.3
LOI	_	_	1.4

5. Conclusions

From the above literatures, it can be abbreviated the following:-

1. It can be used RWG powder until 30% instead of cement as a partial replacement in self-compacted concrete to improve the drying shrinkage, absorption and permeability of concrete.
2. In general, the results showed that increment of 5% of fly ash enhance the characteristics of self-compacted concrete with 30% RWG as cement replacement since; the ground of RWG finer 100 µm shows a pozzolanic behavior.
3. Using RWG as a partial replacement of cement in SCC increases the resistance of concrete to failure due to freeze-thaw cycles because of improving the pore structure with glass.
4. Using RWG as a partial replacement of cement reduces the heat of hydration of SCC.

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References

[1] Suvash Chandra Paul, Branko Šavija and Adewumi John Babafemi, 2018, "A comprehensive review on mechanical and durability properties of cement-based materials containing waste recycled glass", Journal of Cleaner Production, Vol.198, October Issue, pp.891-906.

[2] Osamah Mohammed Ghazi Al-Kerttani, 2018, "Fresh and shrinkage properties of self-compacted concrete when using recycled glass as aggregate", Structural Concrete, Volume 19, Issue 4, Pages: 1245-1254.

[3] Rahman Khaleel AL-Bawi, Ihsan Taha Kadhim, and Osamah AL-Kerttani, 2017, "Strengths and Failure Characteristics of Self-Compacting Concrete Containing Recycled Waste Glass Aggregate", Advances in Materials Science and Engineering, Hindawi publisher, Article ID 6829510, 12 pages.

[4] The Concrete Society and Building Research Establishment (BRE) (2005). Technical report No.62 self-compacting concrete: a review. Day RTU, Holton IX, editors, Camberley, UK.

[5] European Union, EN1992-1: (2004). Eurocode 2:Design of concrete structures Part 1 –1; General rules and rules for buildings, Part 1-2 ; General rules , Structural file design

[6] European Union, EN206-1: (2000). Concrete Part 1 – Specification, performance, production and conformity.

[7] Shi C., Wu Y., Riefler C. and Wang H. (2005). Characteristics and pozzolanic reactivity of glass powders. Cement and Concrete Research, 35(5), pp. 987-993.

[8] Shi C. and Wu Y. (2005), "Mixture proportioning and properties of self- consolidating lightweight concrete containing glass powder", ACI Materials Journal, Vol. 102, No. 5, pp. 355-363.

[9] Shayan A. and Xu A. M. (2006), "Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs", Cement and Concrete Research, Vol. 36, No.3, pp. 457-468.

[10] Jawed I. and Skalny J. (1978), "Alkalies in cement: A review II. Effects of alkalies on hydration and performance of Portland cement", Cement and Concrete Research, Vol. 8, No. 1, pp. 37-51.

[11] Dumitru I., Song T., Caprar V., Brooks P., and Moss, J. (2010)," Incorporation of recycled glass for durable concrete", 2nd International Conference on Sustainable Construction Materials and Technologies, Universita Polytechnica delle Marche, Ancona, Italy.

[12] Nassar, R. U. D. and Soroushian, P. (2012), "Strength and durability of recycled aggregate concrete containing milled glass as partial replacement for cement". Construction and Building Materials, 29, April, pp. 368-377.

[13] Schwarz N., Cam H. and Neithalath N. (2008), "Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash", Cement and Concrete Composites, Vol. 30, No. 6, pp. 486-496.

[14] Nwaubani Sunny O. and Poutos Konstantinos I. (2013), "The Influence of Waste Glass Powder Fineness on the Properties of Cement Mortars", International Journal of Application or Innovation in Engineering and Management (IJAIEM) Vol. 2, No. 2, pp. 110-116.

[15] Liu, M. (2011), "Incorporating ground glass in self-compacting concrete", Construction and Building Materials, Vol. 25, No. 2, pp. 919-925.

[16] Du, H., Tan, K.H., (2017), "Properties of high volume glass powder concrete", Cement Concrete Campsites, Vol. 75, January, pp. 22-29.

[17] Parghi, A., Alam, M.S., (2016), "Physical and mechanical properties of cementitious composites containing recycled glass powder (RGP) and styrene butadiene rubber" (SBR). Construction Building Materials, December Issue, 104, 34-43.

ISSN (1681- 6870)

[18] Tuncan Man., Karasu B. and Yalcin M. (2001), “The suitability for using glass and fly ash in portland cement concrete”, The 11th International Society of Offshore and Polar Engineers (ISOPE) Congress, Stavenger Norvay, Anadolu University, 4, pp. 146-152.

[19] Ozkan O. and Yuksel I. (2008), “Studies on Mortars Containing Waste Bottle Glass and Industrial By-Products”, Construction and Building Materials, Vol. 22, No. 6, pp. 1288-1298.

[20] Corinaldesi V, Gnappi G., Moriconi G. and Montenero A., (2005), “Reuse of Ground Waste Glass as Aggregate for Mortars”, Waste Management, Vol. 25, No.2, pp. 197-201.

[21] Chen S.H., Huang R., Wu J.K. and Yang C.C., (2006), “Waste E-Glass Particles Used in Cementitious Mixtures”, Cement and Concrete Research, Vol. 36, No. 3, pp. 449-456.

[22] Ana Mafalda Matos, Telma Ramos, Sandra Nunes, Joana Sousa-Coutinho, (2016), “Durability Enhancement Of SCC With Waste Glass Powder”, Materials Research, Vol. 19, No. 1, pp. 67-74.

[23] Sales, R.B.C., Sales, F.A., Figueiredo, E.P., dos Santos, W.J., Mohallem, N.D.S., Aguilar, M.T.P., (2017), “Durability of Mortar Made with Fine Glass Powdered Particles”, Advances in Materials Science and Engineering, July Issue.

[24] Narayanan Neithalath, (2008), “Quantifying the Effects of Hydration Enhancement and Dilution in Cement Pastes Containing Coarse Glass Powder”, Journal of Advanced Concrete Technology, Vol. 6, No. 3, pp. 397-408.