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### Research Article:

Evaluating the effect of waste glass on the fresh and mechanical properties of mortar: A review  
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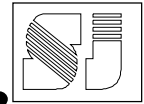
#### Abstract

During quick developing and increasing the requirement of the human life, with the progressing civilization in history, glass instruments (different types, sizes, shapes, and equipment) were one of the helpful parameters in human life. With increasing population and developing equipment, increase the production of glass in the world and recycling of waste glass become one of the main subjected by researchers to develop a quick and economic way to reuse waste glass especially color glass. This article includes a review of previous work for using a different type of waste glass (cathode ray tube, heavy glass, food, medical glass, door and window's glass, spent fluorescent glass, color and un-color glass) as a replacement to fine aggregate in mortar and showing its effect on the fresh and mechanical properties of mortar. The results show that, based on the chemical composition and grinding of particles had a different effect on the early and mechanical properties. The optimum percentage range of using waste glass which can provide property near to control mix vary between 20-30%. The effect of glass granular on fresh and mechanical properties of the mortar is dependent on the particle grading and its chemical composition in which, when 25% of waste glass from brawn bottle used in mortar increase 10% in compressive strength and decrease flexural strength by 6% while using 25% of heavy weight waste glass decrease 10% of compressive strength and 9% of flexural strength of the mortar.

## 1. Introduction

Waste management is becoming a significant issue for communities worldwide, with development of the life, increasing the requirements of the people, it leads increase different type of waste materials, which glass is one of them [1]. Glass has so many applications in daily life such as packaging for food and bottle for drink and tableware [2], building members [3], or as a radiation shield [4], electronic and related application [5], and solar radiation glass [6]. Glass is a non-biodegradable so, it is not suitable for addition to landfill, therefore recycling opportunities need to be investigated [7]. The total annual domestic glass product and usage is growing up more and more. This rise in production and use of glass in recent years is due to the increase in industrialization and the rapid

improvement in the standard of living. Because of this process, accumulating amounts of waste glass, including sheet or window glass, is challenging, which requires effective and rational solutions. From the economic and environmental points of view, the process of waste glass recycling is acquiring an increasing interest in recent years [8]. According to the environmental protection agency (EPA) in the United States the following data are presented in Table.1 (United Stated Environmental Protection Agency, 2003) [9], which shows the amount of waste glass which not recycled and becomes waste in the landfill. Also based on the glass packaging institute and state environmental agency websites [10], the data in figure1 represents amount of glasses produced



by tones in the US from 1960 to 2018 with showing the amount of recycled and non-recycled glass. The amount of non-recycled glass can be used in concrete as aggregate [11-18], or as cementitious material [19-23], and may be used as in pavement and asphalt [24-26], or used in geotechnical application [27], or in tile and brick manufacturing [28-31], or in water filtration and sand blasting [32]. The use of recycled glass aggregates (RGAs) in construction has attracted increasing research interest worldwide [7]. Due to the high material consumption of the construction industry, the utilization of waste glass as a partial replacement for fine aggregate in mortar is particularly attractive [7]. Many researchers studied the use of waste glass in mortar. Among the advantages of using crushed glass as aggregate (fine aggregate) in mortar is that water absorption of glass is nearly zero. This makes it a very durable material. Moreover, glass has excellent hardness, and this gives the mortar and concrete high abrasion resistance [8]. The plain glass dust waste can be recycled, but it is costly to remove the color of colored glasses and recycled them [33]. Since the mortar compose mainly of three main compositions (cement, water, and sand), change in any one of these compositions will change obtained properties in the result [34]. So based on the types of the used glass in previous work this article provides the effects of these types of glass on the fresh and mechanical properties of mortar and selecting optimum percent of used glass as a replacement for sand in which can affect positively the mortar properties.

## 2. Glass properties used in mortar

Since there are different usages of glass in daily life, there are different kinds of waste glass based on its chemical composition. These glasses were used in the mortar had different chemical compositions and different particle sizes. Based on the replacement usage and according to these differences, they have a different effect on the mortar's property. Reviewed papers are as described in the table 2.

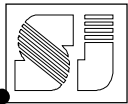
## 3. Review of fresh properties of mortars contains different type of waste glasses:

Flow is one of these properties of mortar which measured in fresh state. Mortar must provide required flow based on **ATSM, C1329** [42] to be before checking other properties. Increase flow property of mortar with the increase of glass content in mortar since the water absorption of glass approximately near to zero which is smaller than water absorption in sand [34-41]. With the replacement of sand partially by cathode ray tube increase flow of mortar, when sand replaced by cathode ray tube 100% increase flow 58% compared to control mix [34] when un-treated cathode ray tube used compare to treated cathode ray tube, provide higher flow [35]. When the maximum

particle size is reduced, the flow is reduced as shown in figure 2 [36]. The effect on the flow changes based on the glasses type, as well **Ling and poon, 2011** when replaced sand by 25% of cathode-ray tube increased 18.3% of flow while when **Sikora et al., 2016** replaced sand by 25% of brown waste glass from the bottle, the flow increase by 5.71%.

Compressive strength is the mechanical property in which is also considered as the main property that can be decided based on, for using the material in the required location or not [31,40]. Using glass as sand replacement in the mortar will affect the mechanical property including compressive strength based on the size gradation and its chemical composition. When cathode ray tube (CRT) is used as sand replacement decrease compressive strength and this process will continue with the increase of replacement percent. The most optimum replacement ratio was 25% at which decrease compressive strength by 1.5% compared to the control mix [34]. If the used waste glass was chemically un-treated it will provide lower compressive strength compared to that if it is chemically treated [35]. Chemical composition also is one of the most important factors which has a role in the obtained result in which used glass in **Corinaldesi et al, 2016** were consists of three different colors (Un-color, Amber, and green). Un-color glass provides higher compressive strength in mortar compared to other colors when used by the same ratio and gradation, Amber color was the second and followed by green color [37]. Using additional cementitious material with the cement in the mortar affects the obtained result and reduces the negative role of the glass [38]. Compressive strength test result when used glass is heavy weight waste glass, as in **Choi et al., 2017** the obtained results showed that prepared samples decrease 2.3- 36% in compressive strength compared to control samples [39]. Using treated spent-fluorescent glass as a sand replacement provides a mortar with mechanical properties better than mortar which contains un-treated spent-fluorescent waste glass [41]. In **Guo et al., 2018**, when sand was replaced completely with bottle waste glass decrease compressive strength by 37% compared to the control mix [45].

Flexural strength is one of the mechanical properties of the material defined as stress in a material just before it yields in a flexural test, and it is effected by glass content in mortar, this effect will vary according to the chemical composition and granular gradation of glass [33]. CRT waste glass when used as sand replacement effect negatively on flexural strength, and this effect increase with the increase of replacement ratio [33,47]. The replacement percent which provides property approximately to the control mix is 25% in which can provide flexural strength 1.8% lower than the control mix [34]. Using untreated



CRT as sand replacement will be more effective compare to treated CRT [35]. Gradation of waste glass particles affects the obtained result when glass with small particle size used as sand replacement in mortar provide flexural strength higher compare to the same glass with larger particle[36]. Waste glass color also affects the obtained result as in Corinaldesi et al, 2016 in which un-color glass provides a higher value of flexural strength compared to amber and green color waste glass. Amber comes in the second and followed by green color waste glass [37]. Flexural strength test decrease ratio varies between 1-35% Based on the replacement ratio of sand by heavyweight waste glass [39]. Used waste glass by Bostanci, 2020, increases flexural strength higher than control mix [48].

Since glass has a smooth surface texture and does not absorb water, when used as sand replacement in the mortar decreases water absorption such as when CRT is used [34]. If used CRT was treated chemically provides a lower effect on the water absorption value, compare to un-treated CRT [35]. When the same glass is used as sand replacement in two different mixes, this one which has a higher particle size provides lower water absorption since smaller particle provide higher surface area and increase friction between particles [36]. Water absorption in glass is approximately zero [45].

With the increase of replacement, ratio increase the density of the mortar when sand replaced by 100% of untreated cathode ray tube (CRT) waste glass increases the density of mortar by 11% compared to the control mix, in which it is dependent on that the density of the glass (cathode ray tube) which is higher than the density of sand [34]. If used CRT waste glass as a sand replacement was treated by acid treatment process for taking out PB oxide inside CRT before crashing process) it will decrease the density of the mortar [35]. When used waste glass particles are reduced, decreasing the density of the mortar [36]. Ling and Poon, 2017 provided that when 40% sand is replaced by the glass the density increase by 2.2% [41]. While Malek et al, 2020 reported that with the increased replacement ratio decrease density since increase the amount of water in the mortar which create higher void ratio in the mortar [43-44-46-49]. The increase of sand replacement by glass particle "decreases dry shrinkage [44] sand replaced by 100% with CRT decrease dry shrinkage by 27% compared to the control mix [34]. But when treated CRT is used as a sand replacement has a lower effect on dry shrinkage compared to un-treated CRT on dry shrinkage [35]. Particle size also affects the dry shrinkage in mortar, when a type of glass with maximum size of 5 mm used as sand replacement provide lower dry shrinkage compare to the same type

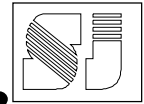
and amount of glass when maximum size be 2.36 mm [36]. When fluorescent waste glass is used as sand replacement in different percent decrease dry shrinkage compares to control samples [41].

Using glass as sand replacement in the mortar increase ASR, when sand replaced completely by CRT increases ASR 575% compared to the control mix [34]. If the used CRT was treated has a lower effect on the ASR compared to untreated [35]. Decrease in granular maximum size decrease the effect on ASR [36]. Waste glass color also effect on the ASR as investigated by Corinaldesi et al, when amber or green glass used provide lower amount of ASR compare to un-color waste glass[37]. Fluorescent waste glass is used as sand replacement increase ASR compare to control mix [41].

### Conclusion

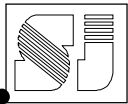
Using waste glass as a replacement for mortar component material is one of the most environmentally friendly ideas for re-use waste material. According to previous research about using glass particles as a replacement to sand in mortar, following conclusion was obtained:

- 1- Treated Cathode ray tube (passed through acid treatment for taking out Pb oxide inside glass) which is obtained from Tv or electronic device can be used as sand replacement in the mortar and decrease compressive and flexural strength with increase amount of replacement.
- 2- By using 50 % of glass (treated cathode ray tube) as sand replacement in mortar, compressive and flexural strength will decrease about 13% compared to the control sample, while the decrease amount will be 25% if an untreated cathode ray tube is used.
- 3- With the decrease in maximum size of used glass decrease fluidity, compressive strength, alkali- silica reaction and density while increase water absorption, flexural strength and dry shrinkage.
- 4- Using un-color glass by 50 % give mechanical property ( compressive and flexural strength ) near to control mix but give higher ASR than that which allowable by standard (0.1% ) by ASTM
- 5- There is not any detection of ASR in any mix which using color glasses
- 6- Due to pozzolanic activity and Nano-filler effect will affect the bond between cement paste and glass particles and it will affect positively the obtained mortar property.
- 7- With increase of heavyweight glass ratio, during using heavyweight glass as a replacement to sand, decrease compressive and flexural strength.
- 8- Using spent fluorescent glass as a replacement to fine aggregate in mortar results in increase fluidity, decrease dry shrinkage and mechanical properties (compressive strength and flexural strength) with increase replacement ratio.

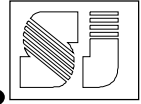


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تقييم تأثير نفايات الزجاج على الخواص الطرية والميكانيكية للمونة: مراجعة

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سيروان خورشيد رفيق زهاوي 2، أ

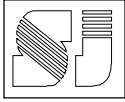
أجامعة السليمانية ، كلية الهندسة ، قسم الهندسة المدنية

### المستخلص

أثناء التطور السريع وزيادة متطلبات الحياة البشرية ، مع تقدم الحضارة في التاريخ ، كانت الأدوات الزجاجية (أنواع وأحجام وأشكال ومعدات مختلفة) واحدة من المعايير المفيدة في حياة الإنسان. مع زيادة عدد السكان وتطوير المعدات ، فإن زيادة إنتاج الزجاج في العالم وإعادة تدوير نفايات الزجاج من احدى المواضيع الرئيسية للباحثون لتطوير طريقة سريعة واقتصادية لإعادة استخدام زجاج النفايات وخاصة الزجاج الملون. تتضمن هذه المقالة مراجعة للأعمال السابقة لاستخدام انواع مختلفه من نفايات الزجاج (أنبوب أشعة الكاثود ، والزجاج الثقيل ، والمواد الغذائية ، والزجاج الطبي ، وزجاج الابواب والنوافذ، والزجاج الفلوري المستنفد ، والزجاج الملون وغير الملون) كبديل لركام الناعم في المونة ويظهر تأثيره على الخواص الطرية والميكانيكية للمونة. أوضحت النتائج أنه بناءً على التركيب الكيميائي وطحن الجزيئات كان لهما تأثير مختلف على الخواص الطرية والخواص الميكانيكية. تتراوح النسبة المئوية المثلى لاستخدام نفايات الزجاج والتي يمكن أن توفر خاصية قريبة من مزيج التحكم بين 20-30%. يعتمد تأثير الزجاج الحبيبي على الخواص الطرية والميكانيكية للمونة على تصنيف الجسيمات وتكوينها الكيميائي ، حيث يزيد بنسبة 25% من نفايات الزجاج من الزجاج ذات القوام المستخدم في الملاط بنسبة 10% في مقاومة الانضغاط وتقليل قوة الانحناء بمقدار 6% أثناء استخدام 25% من زجاج نفايات الوزن الثقيل ينقص 10% من مقاومة الانضغاط و 9% من قوة الانحناء للمونة.

### الكلمات المفتاحية:

قوة الانضغاط ، التدفق ، قوة الانحناء ، المونة ، استبدال الرمل ، نفايات الزجاج ، الانكماش الجاف .



**Table.1 Amount of glasses production and recycle in European country in 2001[9]:**

Country	Production amount (Tonnes)	Recycling Rate (%)
Australia	200 000	83
Belgium	279 000	88
Denmark	125 000	65
Finland	46 000	91
France	1 950 000	55
Germany	2 666 000	87
Greece	44 000	27
Ireland	46 000	40
Italy	1 100 000	55
Netherland	400 000	78
Norway	44 000	88
Portugal	122 000	34
Spain	506 000	33
Sweden	144 000	84
Switzerland	294 000	92
Turkey	73 000	24
United Kingdom	736 000	34

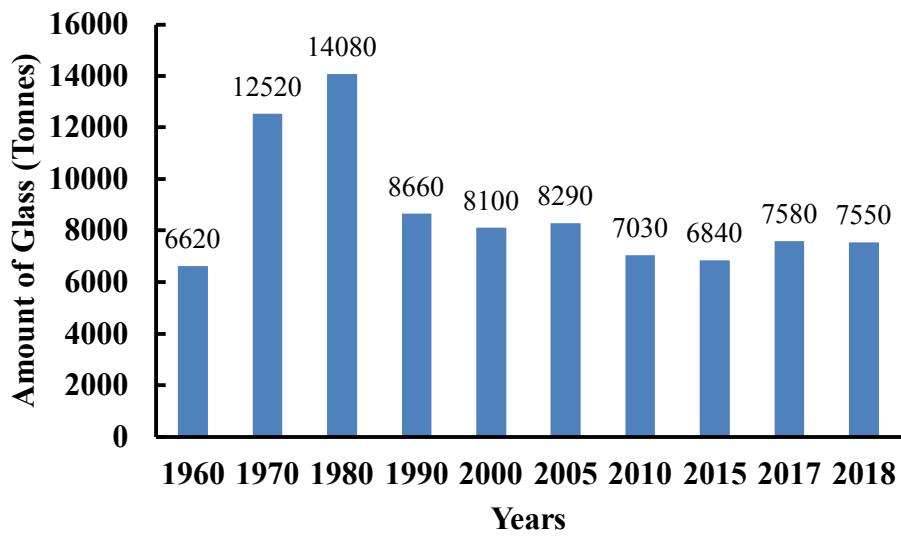
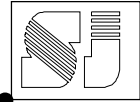


Fig.(1): Waste glass amount in United States based on given year [10]



**Table.2 Types, size and properties of used glass in reviewed papers:**

References	Glass type	Glass Size	Replacement Percent (%)	Properties
[34]	Un-treated Cathode ray tube	0.15 – 5 mm	0, 25, 50, 75 and 100	Relative Density = 2.99 gr/cm <sup>3</sup> Fineness modulus = 3.2 % Water absorption ≈ 0
[35]	Treated Cathode Ray tube	0.15 – 5 mm	0,50 and 100	Relative Density = 2.99 gr/cm <sup>3</sup> Fineness modulus = 3.61 % Water absorption ≈ 0
[36]	Treated Cathode Ray tube	Maximum size 5 mm	0, 25, 50, 75 and 100	Fineness modulus = 3.41 %
[36]	Treated Cathode Ray tube	Maximum size 2.36 mm	0, 25, 50, 75 and 100	Fineness modulus = 2.91 %
[36]	Treated Cathode Ray tube	Maximum size 1.18 mm	0, 25, 50, 75 and 100	Fineness modulus = 2.31 %
[36]	Treated Cathode Ray tube	Maximum size 0.6 mm	0, 25, 50, 75 and 100	Fineness modulus = 1.62 %
[37]	Different color cullet glass (Un-color, green and amber)	0.3 - 8 mm	50 and 100 for each one	-
[38]	Brown waste glass from bottle	0.16 - 2 mm	0, 25, 50, 75 and 100	-
[39]	Heavy weight waste glass	0.15 – 4.76 mm	0, 25, 50, 75 and 100	Specific Gravity = 3 Fineness modulus = 3.34 %
[41]	Heat treated spent fluorescent	0.15 – 2.36	0, 10, 20, 30 and 40	SSD Density = 2978 kg/m <sup>3</sup> OD Density = 2992 kg/m <sup>3</sup> Fineness modulus = 3.18 % Water absorption = 3.52%
[41]	Un-treated spent fluorescent	0.15 – 4.75	0, 25, 50 and 75	SSD Density = 3042 kg/m <sup>3</sup> Fineness modulus = 3.38 % Water absorption = 1.47%

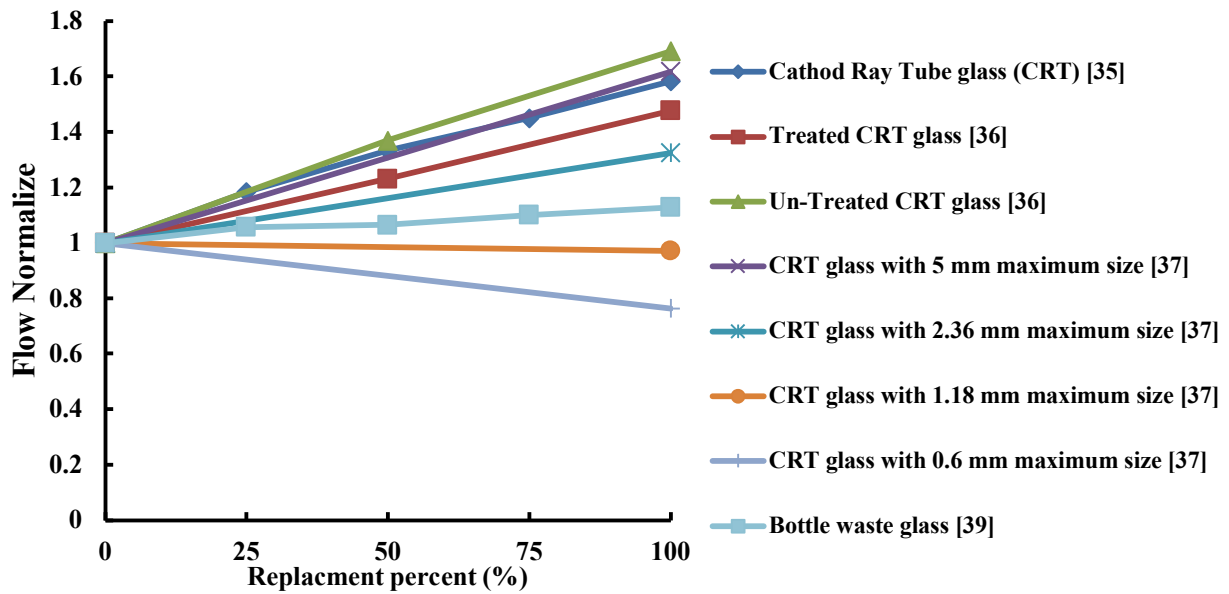
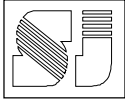


Fig. (2): Normalize flow based on the replacement percent

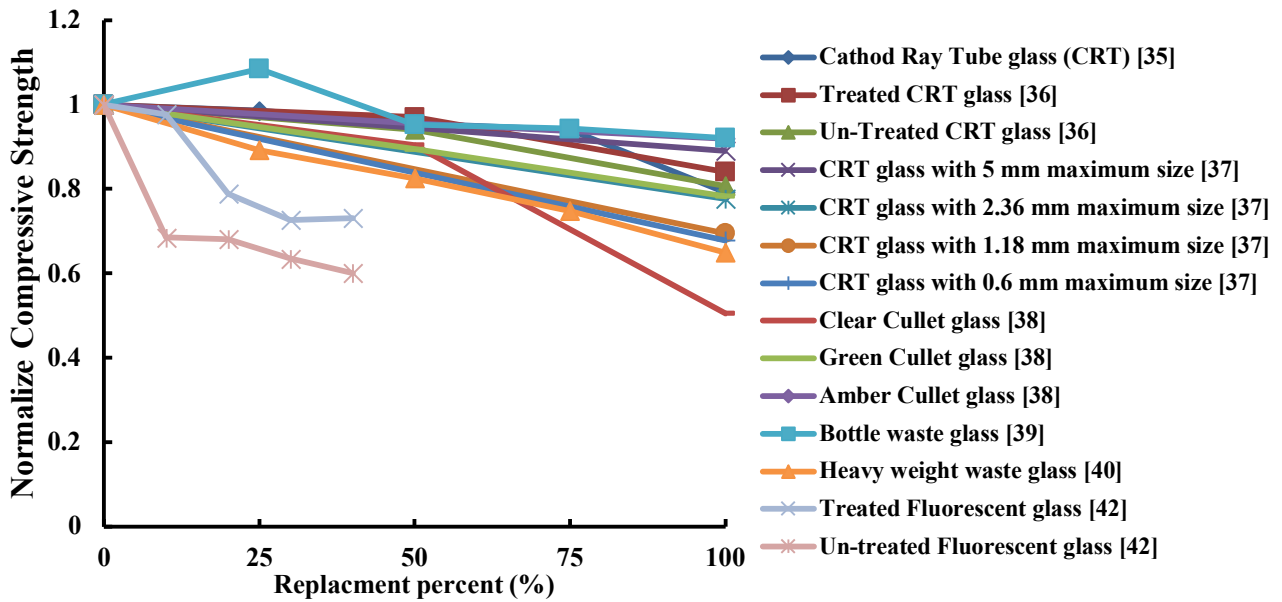


Fig.(3): Normalize compressive strength based on the replacement percent

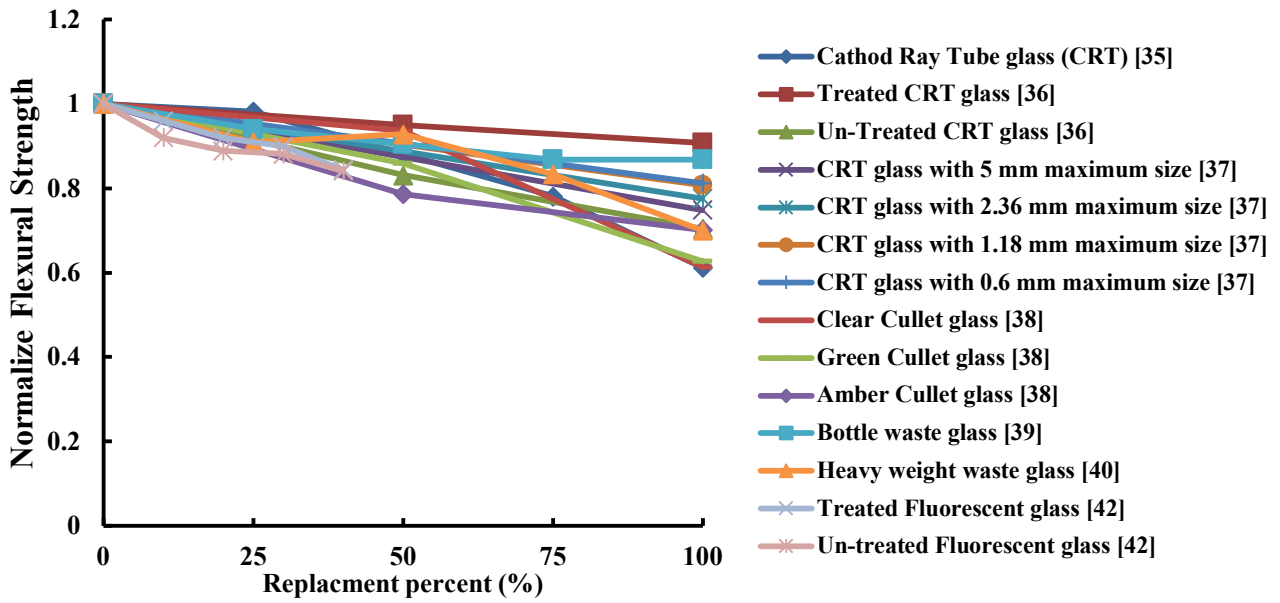
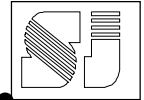


Fig.(4): Normalize flexural strength based on the replacement percent

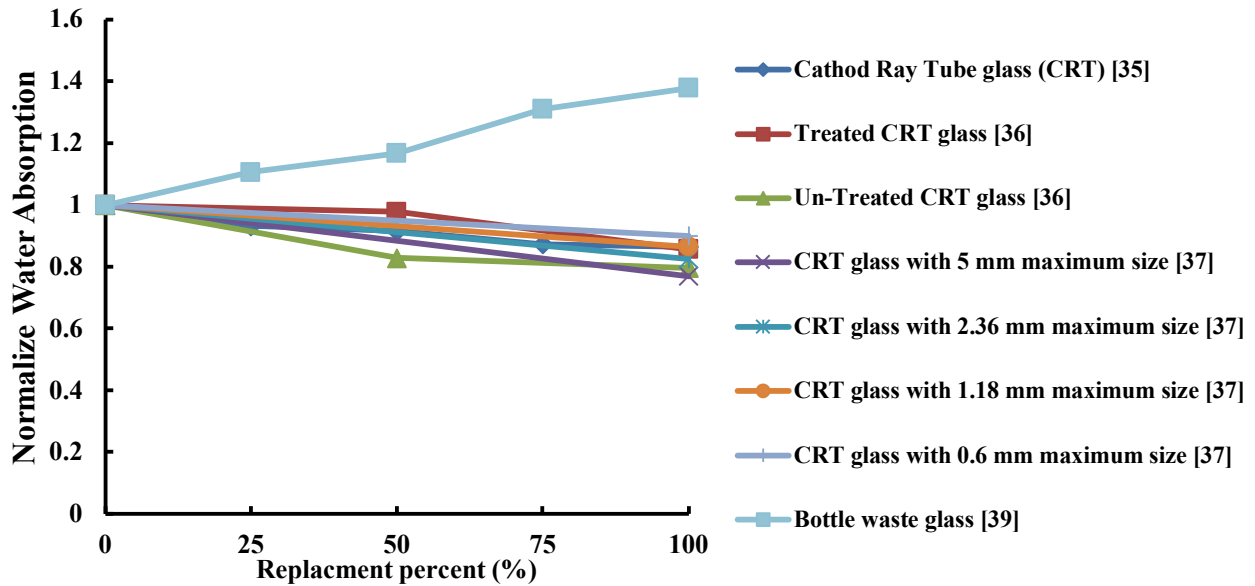


Fig.5 Normalize water absorption based on the replacement percent

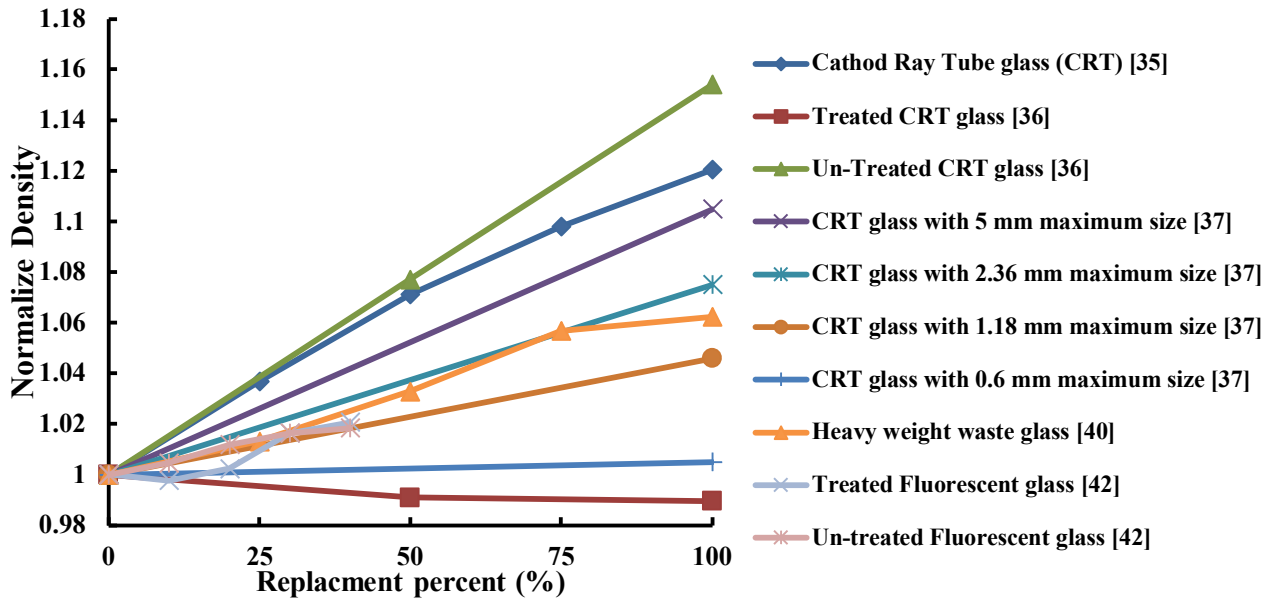
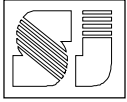


Fig.(6): Normalize Density value based on the replacement percent

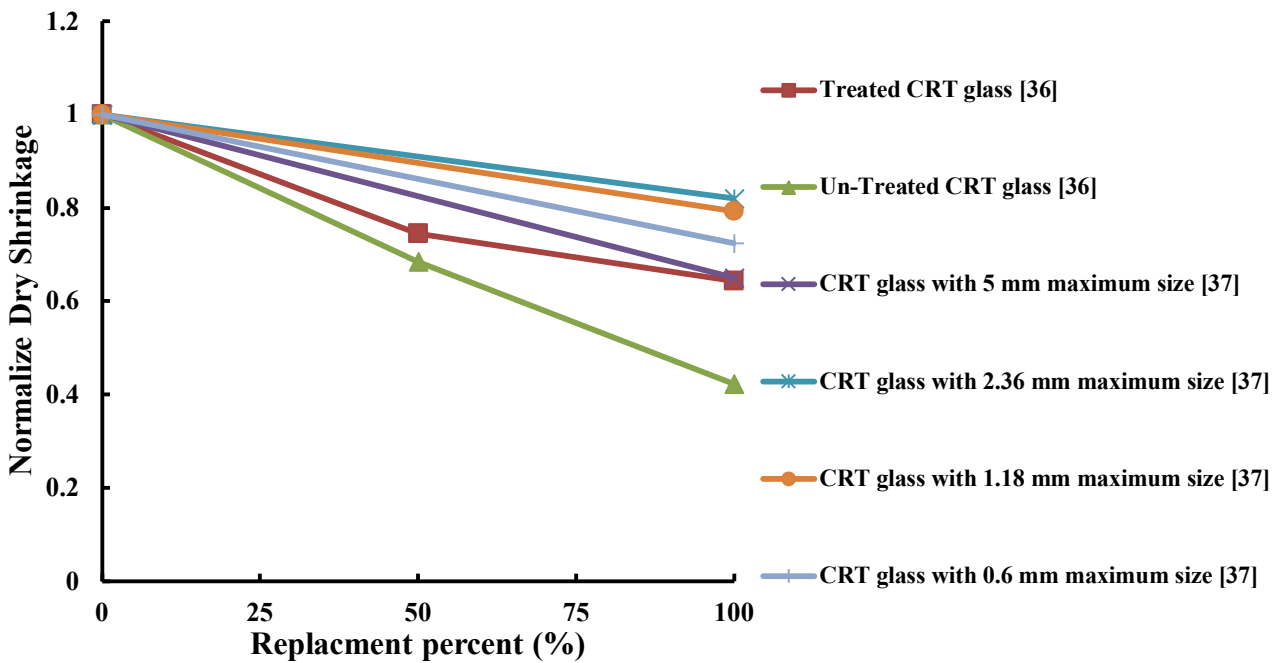


Fig.(7): Normalize Dry shrinkage based on the replacement percent

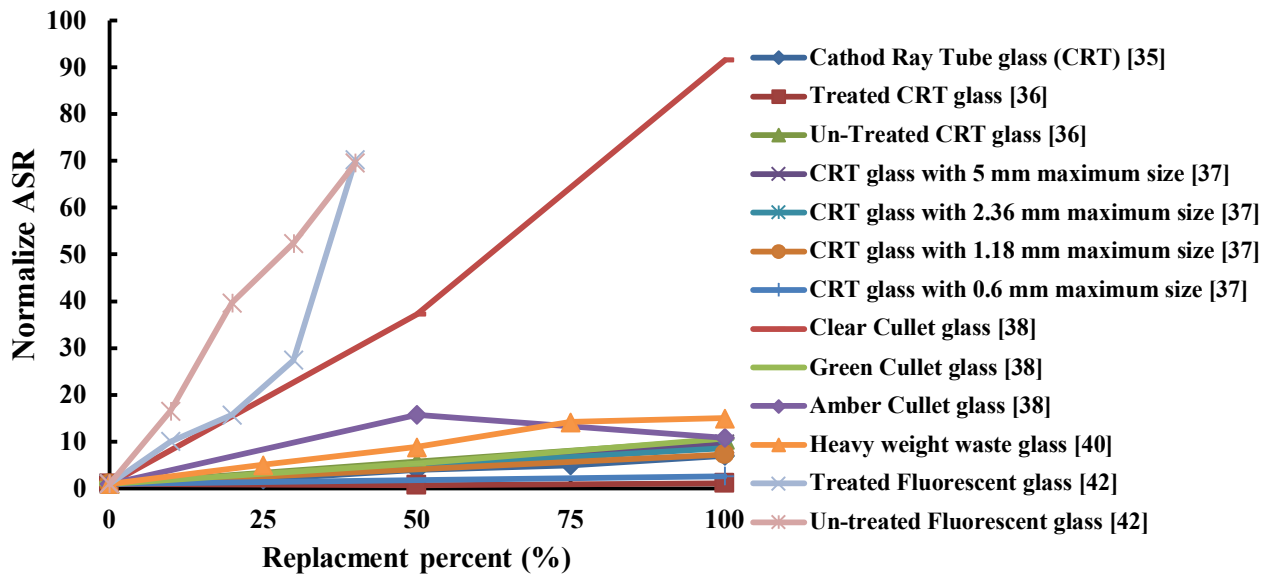
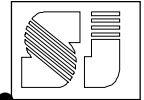
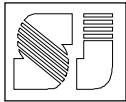


Fig.(8): Normalize ASR value based on the replacement percent



**Table 3** Type of glasses used in reviewed papers, with them optimum limitation

Ref.No	Papers Author	Type of Glass	Optimum limitation	Flow (%)	Compressive Strength (%)	Flexural Strength (%)	Density (%)	Water Absorption (%)	ASR (%)	Dry shrinkage (%)
34	Ling and poon, 2011	Un-treated cathode ray tube	25%	+18.3	-2.3	-2.9	+3.8	-6.86	+87.5	-4.16
35	Ling and poon, 2012	Treated Cathode ray tube (CRT)	50%	+23.1	-3.01	-4.7	-1.62	-2.33	+38.18	+20
35	Ling and poon, 2012	Un-Treated CRT	50%	+36.9	-6.02	-16.9	+6.9	-17.19	+176	-17.19
36	Ling and poon, 2013	Treated CRT with 5 mm maximum size	100%	+61.7	-10.62	-25.42	+10.29	-22.41	+9458	-34.58
36	Ling and poon, 2013	Treated CRT with 2.36 mm maximum size	100%	+32.17	-21.7	-22.7	+7.56	-17.5	+8694	-18.5
36	Ling and poon, 2013	Treated CRT with 1.18 mm maximum size	100%	-3.47	-29.95	-20	+4.6	-13.65	+7252	-21.25
36	Ling and poon, 2013	Treated CRT with 0.6 mm max. size	100%	-24.3	-31.64	-19.57	+0.6	-10.12	+2538	-28.33
37	Corinaldesi et al, 2016	Different color cullet glass (un-color, green and amber)	50%	-	-9.61	-6.42	-	-	+200	-
38	Sikora et al., 2016	Brown waste glass from bottle	25%	0	+8.53	-5.95	-	+10	-	-
38	Sikora et al., 2016	Brown waste glass from bottle with nano silica	25%	+5.71	-5.12	-3.48	-	+9.85	-	-
39	Choi et al., 2017	Heavy weight waste glass with w/c = 0.45	25%	-	-10.82	-9.09	+1.31	-	-	-
39	Choi et al., 2017	Heavy weight waste glass with w/c = 0.35	25%	-	-10.85	-8.57	+1.44	-	-	-
39	Choi et al., 2017	Heavy weight waste glass with fly ash and w/c = 0.35	25%	-	-10.10	-5.43	+3.35	-	-	-
39	Choi et al., 2017	Heavy weight waste glass with GGBS and w/c = 0.35	25%	-	-8.83	-7.43	+1.22	-	-	-
41	Ling and poon, 2017	Heat treated spent fluorescent	30%	-	-16.5	-4.65	+1.16	-	-	-
41	Ling and poon, 2017	Un-treated spent fluorescent	30%	-	-30.06	-7.56	+1.16	-	-	-