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Recycling of Glass in Concrete

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***Abstract*— Glass is widely used in our daily life. It is an ideal material for recycling. Recycling of glass is used in various forms in different fields. One of the important applications of recycling of glass is in concrete production of construction field. In this article, coarse and fine aggregates of concrete had been replaced up to 20 percent by the crushed glass. In depth observation had been done on properties of concrete i.e., compressive strength, flexural strength, air content and also alkali-silica reaction (ASR). Replacement of waste glass (WG); silica in glass and alkalies in cement combined to create large expansion which causes the large cracks in concrete. This is the main disadvantage of usage of waste glass in concrete. We had overcome this problem up to some level by varying the particle size of glass which is also an influencing factor for expansion. We also used some cementitious materials like fly-ash, microsilica along with waste crushed glass. This research is mainly focused on observing mechanical properties of concrete and controlling of alkali-silica reaction.**

Keywords*— *Waste Glass, Concrete, ASR, Fly Ash, Microsilica

1. INTRODUCTION

Every year million tons of glass enters the municipal solid waste (MSW) stream in United States. In that most of the glass was sent to the landfills and partially reused or recycled. In USA total MSW is 250 million tons in 2013; out of that only 47.47% was recycled and remaining was sent to the landfills. Due to lack of market for recycling of glass in some states like Hawaii; it has been sent to landfills. To find the solution for it, some of it was used as crushed waste glass in manufacturing new glass products with high quality. Alternative solutions for this are applications of water filtration media, landscaping material, and as *aggregate* in construction including pavement layers etc. Specifically in some areas availability of natural aggregates are limited, in those cases recycled glass is used as partial replacement of aggregate. Using waste glass in concrete construction field is advantageous as the production cost of concrete will go down and that too crushed glass or cullet, if properly sized and processed can exhibit similar characteristics of gravel or sand. But major challenges faced in previous researches were reaction between alkali-silica has increased because of using glass which leads to not only cracks upon expansion but also weakens the concrete and shortens its life. To explore solutions to mitigate ASR induced by glass aggregate, the University of Hawaii has initiated a research study with the ultimate goal of developing durable concrete mixtures containing recycled glass as fine aggregates. Concrete without waste glass gains more strength than with waste glass. Concrete properties like compressive strength, flexural strength and air content are all affected by adding waste crushed glass to the concrete. Because of waste glass the concrete strength will increase by maintaining the glass particle size. The current paper presents some experiments related to concrete mechanical properties by adding waste crushed glass and the controlling procedure of ASR expansion in order to reduce the concrete cracks thereby increasing the life of concrete.

2. LITERATURE REVIEW

The use of crushed glass in architectural concrete was from 1950s. The first report on using waste glass as coarse aggregate in concrete was published by Johnson 1974. Later report by Figg (1981) concluded that in many cases the use of coarse glass aggregates resulted in considerable ASR expansion and cracking. An expensive study on replacing coarse aggregate with glass was reported by Topcu and Canbaz (2004), where crushed green soda glass was reduced to 4-16mm to replace the coarse aggregate in proportions of 0-60%. Topcu and Canbaz showed that the compressive strength of concrete decreases when the replacement quantity of fine aggregate with waste glass increases. Actually compressive strength decreased by 8% for 15% glass replacement of fine aggregate and by 15% for 30% glass replacement of fine aggregate. Shayan and Xu (2006) reported that the replacement of sand with waste crushed glass did not influence the slump. Taha and Nounu (2008) showed that the compressive strength of their concrete mixes did not show distinguished difference when recycled crushed glass sand was used to replace natural sand. However Park et.al (2004) showed that 4-week old concrete with 30, 50, and 70% crushed glass replacement of virgin aggregate displayed a reduction in compressive strength resulting in 99.4, 90.2, and 86.4% relative to that of plain concrete. Recycling of crushed glass in concrete led to ASR expansion. This is not only because of alkali-silica reaction but also other effecting parameters. In those parameters glass particle size is an important factor. Influence of glass particle size on ASR expansion has been widely investigated. Jin et.al (2000) showed that glass particles in the size range of 1.18-2.36mm produced the greatest expansion and the particles less than

0.3mm showed the performance of no expansion. In another report Bazant et al. (1998) reported that the glass particle size of approximately 1.5mm caused more expansion, whereas diameter less than 0.25mm caused no expansion in laboratory tests on concrete. Dhir et al. (2009) suggested that the coarse glass particles cause greater expansion than the fine glass particles. Because coarse glass particles contained wider preexisting cracks so there would be a chance of more penetration of more pore fluid and therefore greater diffusion of hydroxial ions to the interior of the glass particles. Studies have concluded that the ASR expansion will increase by increasing the glass content in concrete. In this paper an attempt has been done in order to reduce the expansion by addition of cementitious materials Fly ash and Micro silica and also observed the mechanical properties of concrete on the addition of waste crushed glass of varying particle sizes.

3. MATERIALS AND METHODS

Here, rest of concrete specimens were made up of same materials as we prepared in local ready mix concrete plant with an aggregate size of 19mm. Cement with an alkali equivalent (Na_2Oeq) content of 0.53% and MS and FA are used with their chemical composition as shown in table 1. Fineness of MS was passing the 45µ sieve was 95.2% and for FA it was 84.9%. Soda lime silicate glass which was unwashed from bottles of mixed color was used with specific gravity, water absorption, and unit weight of 2.49, 0.9% and 1610Kg/m^3 respectively which were shown in table2. To decrease the cost of concrete in this experiment, we did not crushed waste glass to a finer size after being supplied for testing. Admixtures like air entraining admixture (100mL/m^3 concrete) and commercial water reducing admixture (530mL/m^3 concrete) with addition of modified polycarboxylates were also used.

Table 1. Chemical Composition of Cementitious Materials Used

Chemical component	OPC	MS	FA
SiO2	22.8	87.9	40.1
Al2O3	4.2	4.3	20.4
Fe2O3	2.3	0.6	10.1
CaO	64.8	0.3	19
MgO	1.0	<0.02	3.4
Na2O	0.2	0.1	2.1
K2O	0.5	0.5	0.5
SO3	3.0	0.1	0.8
LOI	3.0	5.0	0.3
>45µm	-	4.8	15.1

Table 2. Sieve Analysis of Waste Glass

Sieve size(mm)	Accumulated passing (%)
19	100
13.2	99
9.5	88
6.7	54
4.75	30
2.36	8
1.18	3
0.6	2
0.3	1
0.15	1
0.075	0

Procedure

Nine concrete mixtures were used with mixing proportions which was shown in table3. Here water cement ratio (w/c) 0.69 was used and 20% replacement of coarse and fine aggregates with waste glass which was matching the particle size distribution in sieve analysis. FA was tested at 5, 10, and 20% replacement with cement and also MS was tested at 4 and 8% replacement with cement.

Table 3. Concrete Mix Details

Mix number	WG (% replacement of total aggregate by mass)	SCM(% replacement of OPC by mass)	Mix description
1	0	-	Reference mix, 100% OPC
2		FA(20)	20% FA in binder
3		MS(8)	8% MS in binder
4	20		WG, 100% OPC
5		FA(5)	WG, 5% FA in binder
6		FA(10)	WG, 10% FA in binder
7		FA(20)	WG, 20% FA in binder
8		MS(4)	WG, 4% MS in binder
9		MS(8)	WG, 8% MS in binder

With the help of concrete mixer vertical rotation of mixing was conducted. First 90s mixing was done by 80% of mix water with all ingredients; after that remaining mix water was added. Air content of concrete was measured according to ASTM C231 after preparing concrete mix. After that to measure the dry density according to ASTM C642 cylinders were taken from curing water before testing of compressive strength. By using the size (height, diameter) and mass of the cylinders mean dry density was calculated at the age of 28days. Between 7 and 28days compressive strength of three cylinders were measured for each mixture and flexural strength was tested after 28days. For the testing of ASR expansion for each mixture three 75x75x285 mm prisms were cast with the addition of sodium hydroxide solution to the mixing water for raising the alkali equivalent content to 1.25%. After 24h prisms were remolded and initial reading was measured. Prisms were stored for 1 year at 38.0±2.0ºC. During this period, expansion of concrete specimen was measured every month with the help of comparator. By comparing the mixture with glass and control mixture whether the silica in the glass and alkali in the cement were reacting or not and the supplementary cementitious materials FA and MS playing a role in reducing the expansion of ASR or not has been observed. In the period of one year, glass reaction and ASR expansion for each mixture could be known with the help of scanning electron microscope (FE-SEM) in backscattered mode, equipped with an energy dispersive x-ray (EDX).

4. RESULTS AND DISCUSSIONS

4.1. Air content and Dry Density

Air content and dry density values were shown in table4. Actually concrete with waste glass gives more air content in the presence of FA and MS than the normal concrete. This is because the glass particles have irregular shape than the normal aggregates due to that reason there will be more surface area creating chance of getting more air content. Concrete mixes with waste glass results in lower dry density than the normal concrete mix because glass has low specific gravity than the coarse aggregates(ex: rock).

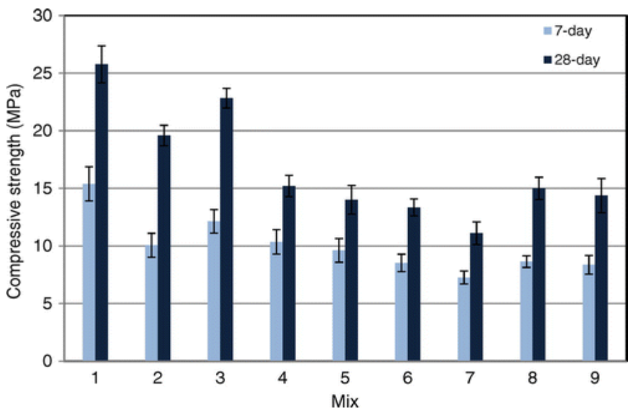
Table 4. Air Content and Dry Density of Concrete Mixes

Mix number	Air Content (%)	Dry Density(Kg/m3)
1	4.3	2.369
2	3.8	2,384
3	4.0	2,372
4	6.3	2,217
5	6.1	2,205
6	5.9	2,211
7	5.7	2,215
8	5.8	2,205
9	5.7	2,197

4.2. Compressive strength

Test results were shown in fig1. Actually compressive strength was measured between 7 and 28 days for early and normal strength. For 100% OPC concrete mix compressive strength will be 15.4MPa. But concrete mix with waste glass was 48% less than the normal concrete mix. This shows the reduction in compressive strength by adding waste glass to the concrete. This reduction was because of brittle nature of glass which was leading to cracks in concrete and also the less adhesion between waste glass and cement which was leading to heterogeneous distribution of aggregates. As the FA and MS content increases, compressive strength decreases because, supplementary cementitious materials takes longer to gain their extra strength by reaction with calcium hydroxide from the hydration of cement. So from the results we can conclude that long term strength will be developed by adding FA and MS.

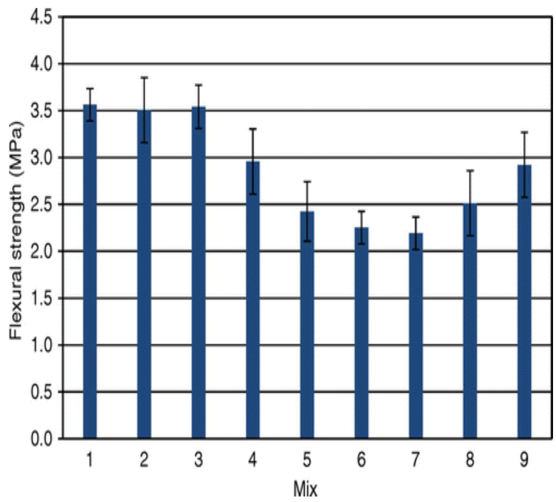
Fig. 1. Mean 7-day and 28-day compressive strength



4.3. Flexural strength

Flexural strength results were shown in fig2. Actually waste glass does not affect flexural strength as much as compressive strength. Concrete mix with waste glass decreases flexural strength than the concrete mix without waste glass due to lack of adhesion between smooth waste glass surface and cement paste. From the results mix4 (WG, 100%OPC) had lower flexural strength than mix1 (100%OPC) and also mix7 had a (WG, 20% FA in binder) 38% lower flexural strength than the mix2 (20% FA in binder). In normal concrete mix, FA and MS do not affect the flexural strength, but with waste glass concrete mix decreases the flexural strength of concrete as shown in fig2.

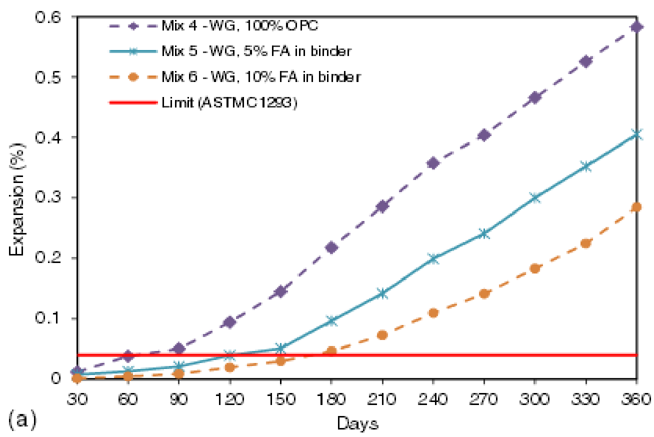
Fig. 2. Mean 28-day flexural strength

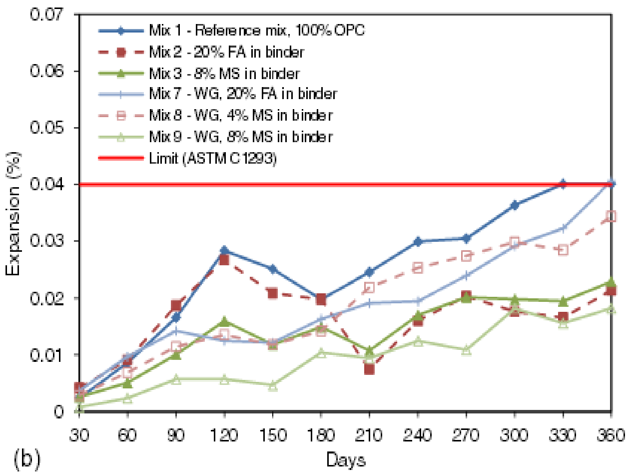


4.4. Alkali-Silica Reaction

Alkali-silica reaction results are shown in fig3. From figure we observed that waste glass without supplementary cementitious materials shows greater expansion than the waste glass with FA and MS. For example mix4(WG, 100%OPC) showed expansion of 0.583% and mix5 waste glass with 5% FA shows expansion of 0.405%. If we further increase the FA content i.e., 10% to 20% the expansion had shown as 0.285% and 0.0406% respectively. Same thing is applicable to MS. For 8% MS in binder and mix8 waste glass with 4% MS in binder shows expansion of 0.0214 and 0.0229%. But for 8% MS in binder with waste glass shows lower expansion than the 4% MS in binder with waste glass. From these results we concluded that increasing FA or MS in binder reduces the expansion of ASR.

Fig. 3. (a) ASR expansion results of mixes with a total expansion of more than 0.04%; (b) mixes with a total expansion less than 0.04%





(b)

Scanning electron microscope and energy-dispersive x-ray are used to know the nature of hydrated binder and waste glass particles mainly when the ASR gel formed after the ASTM C1293 test. Formation of hydrated paste shown in fig4 with no indication of ASR gel or no occurrence of cracks when there is no waste glass in mix. But in fig 5 mix4 with waste glass shown the formation of ASR gel and also occurrence of cracking of concrete, but there is no ASR gel on the surrounding of waste glass particle. The interface of the waste glass particle with the cement paste in mix7 shown in fig 6 with the supplementary cementitious materials showed that there is no formation of ASR gel due to pozzolanic and effect of FA and exhibit similar nature to the normal concrete mix.

The chemical composition of ASR gel within the WG particle in mix 4 presented in Table 5, showing great enrichment of silica in the ASR gel and small traces of calcium, while also retaining a small amount of sodium (Na). The interface of WG with the cement paste in mix 7(WG, 20% FA in binder) is shown in fig.6. With no indication of ASR gel formation, due to pozzolanic and ASR mitigating effect of the FA and also exhibiting features similar to those of reference mix.

Fig.4 SEM image of morphology of mix1 (100% OPC)

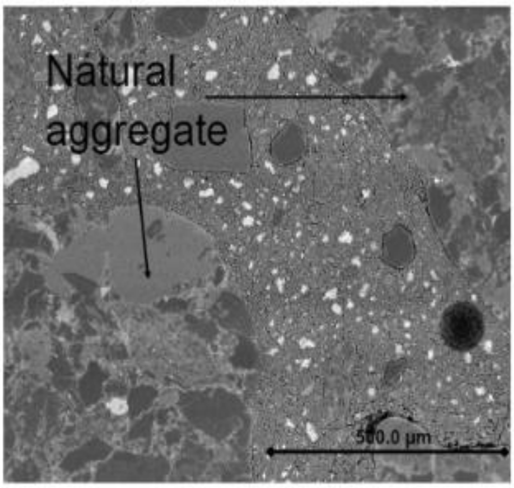


Fig.5 SEM image of morphology of mix4 (WG, 100% OPC)

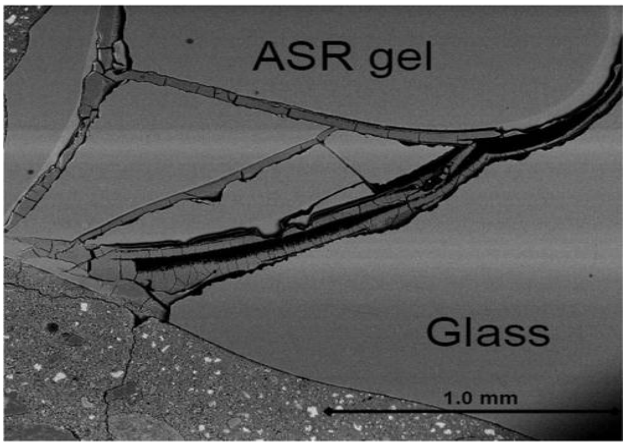
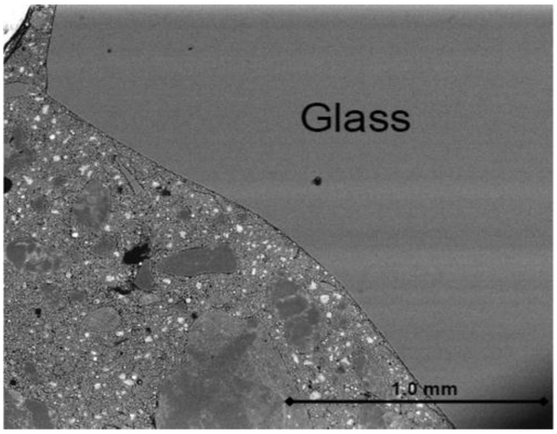


Table5. EDX chemical analysis of the ASR gel in Mix4

Chemical composition	Percentage(%) by weight
SiO2	63.24
CaO	17.48
Na2O	11.24
SiO2/CaO	3.62

Fig6. SEM image of morphology of mix7 (WG, 20% FA in binder)



5. CONCLUSION

Many people do not have awareness on how to utilize the waste resources such as paper, glass etc. This paper mainly focused on the usage of waste glass in concrete with partial replacement of coarse and fine aggregates. Effect of Waste glass on the properties of concrete i.e., compressive strength, flexural strength, air content and ASR expansion has been discussed. Replacement of waste glass in concrete reduced the compressive and flexural strength and increased the ASR expansion. Addition of supplementary cementitious materials such as FA and MS reduced the ASR expansion.

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