Aptness of Waste Glass Powder on Strength of Portland Cement Concrete

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Abstract: ***Portland cement is main binder in concrete whose production is not environment friendly as one ton of cement produces almost 0.7 ton of CO_2 which cause global warming through green house gasses, therefore, cement replacement either partially or completely is required to lower production of cement. In this research cement was partially replaced with 10%, 20% and30% white waste glass powder finer than 150µm. At fixed W/C ratio 0.43 and mix proportion with cement: sand: coarse aggregate= 1:1.19:2.68, it was found with 20% cement replacement compressive strength improved than reference mix. Also porosity and void ratio reduced.***

Keywords: Cement replacement, Supplementary Cementatious Material (SCMs), Glass powder, Compressive Strength, Porosity

1. Introduction

Portland cement is main binder in concrete whose production is not environment friendly as one ton of cement produces almost 0.7 ton of CO_2 which cause global warming through green house gasses [1, 2]. Therefore, from past 30 yrs focus on alternative binder materials such as fly ash, silica fume, slag, zeolite, glass powder etc. is being established that can partially or completely replace Portland cement in concrete. These additives react in the pore solution of hydrating cement either hydraulically or pozzolanically [3, 4, 5, 6, 7, 8, 9]. Materials which completely or partially replace cement from concrete are called supplementary cementatious materials (SCMs). By replacing (a part) of cement in concrete with SCMs, three types of benefits can be achieved: engineering, economic, and ecological.

The limiting factor for the use of pozzolans in concrete is lower reactivity of materials compared to cement. Chemical activators (calcinations), acidic, mechanical (prolong grinding) and thermal (elevated temperature) treatments can be effectively used to increase the reactivity of natural pozzolans [10]. Dissolution rate and solubility of SCMs can be increased by reducing particle size by prolonged grinding [11]. Also change in properties of SCMs by using chemical solutions can accelerate pozzolanic reaction. But chemical solutions change the surface properties of SCMs [12].

Recycled waste glass is an abundant waste material that can be potentially utilized in concrete. It can be efficiently used as cement replacement in concrete because of its amorphous structure, good percentage of silicon and calcium hence, act as a pozzolanic material [13, 14, 15].

No change in slump is observed when cement is replaced by waste recycled glass powder in mortar mixes but increase in slump is observed in some studies due to low water absorption [15, 16, 17]. However, the slump value of the concrete reduces significantly with a partial substitution of cement and sand by waste glass powder when used as binder and fine aggregate, respectively [18, 19,20]. As replacement ratio increases in case of coarse aggregate slight increase in slump is observed for a constant w/c ratio because workability depend on size of aggregate. While opposite happen for fine aggregates because as the fines replacement ratio increases, the loss of workability occur if w/c ratio is increased to achieve required slump[21]. Due to smooth and impermeable surfaces, bond between glass and cement is weak, therefore, slump flow of self-compacting concrete (SCC) increases when sand is replaced by glass aggregates [22, 23]. Bleeding and segregation is proportional to glass sand content [23]. Considerable amount of air gets entrapped into fresh mortar with the incorporation of fine glass aggregates, which may be due to lamellar shape and higher aspect ratio of glass sand [24].

Initial and final setting times of concrete increase as the glass content increases but up to 20% addition of glass powder in concrete does not lead to significant changes in the setting time of cement paste [25, 26, and 27]. With small particle size glass powder acts as nucleation sites for hydration product (mainly C-S-H) formation, thereby increasing the rate of the hydration reaction [28]. Due to higher percentage of glass sand (i.e. 30% OPC replacement) slower pozzolanic reaction occur which reduces the total heat generated and also drop in CH content [28, 29, 34]. During early ages of hydration process dilution of cement occur while in later stages calcium hydroxide (CH) is consumed in the pozzolanic reaction of the waste glass [30, 31].

Concrete containing waste aggregate glass has high alkali silica reaction (ASR) [32, 33]. Glass powder being siliceous in nature and amorphous in structure it reacts with calcium hydroxide of Portland cement forming siliceous gel which in turn absorbs water from cement paste and swells [13, 14, 15].Excess swelling pressure causes micro cracking, expansion and ultimately deterioration of the surrounding concrete. Particle size plays a vital role in ASR occurrence. Coarse particles will be only partially dissolved in the hydration process, fine particles may be completely consumed by the pozzolanic reaction even before ASR gets triggered [31].

Nassar et. al. stated that a significant increase in the later age strength is achieved through formation of a denser and less permeable microstructure which is a result of the filling effect of sub-micron sized glass particles[15]. Park et. al. reported that compressive strength gradually decreased by 2-

49% when fine glass powder replaced 10%-100% fine sand . Also it was found 12.2 to 41.4% air content increased for concrete containing glass sand content of 30%, 50% and 70% [19]. Khan et.al. have concluded that a maximum of 20-30% glass powder could be used in concrete, either as fine aggregates or binder, without any detrimental effect on the compressive strength [35]. Siad et al. reported about 7% to 12% enhancement in flexural strength in high volume fly ash based engineered cementitious composite (ECC) where fly ash was replaced in the mix with 15% and 30% recycled glass powder. The discharge of the high amount of alkalis and aluminates from glass powder and fly ash formed a new form of C-S-H [36]. Tan et. al.studied the influence of distinct types of glass (brown, green, clear and mixed) as fine aggregates on the properties of mortar. The study showed that with 25% of brown, green, clear and mixed glass powders, the splitting tensile strength of mortar increases. However, the splitting tensile strength reduces with higher percentages of glass sand, regardless of the glass colour. For the clear glass sand mortar, the splitting tensile strength decreased consistently with increasing glass content. Also with 100% brown and clear glass sand, air content increased by 30% to 100%. [37]. Du et.al observed a reduction in air void with low replacement ratios (i.e. 25%), but an increment with higher ratio (i.e. 100%). It was because the glass particles (used in their study) have smoother surface compared to natural sand, resulting in better packing and less retention of air voids; however, glass particles also have a more irregular shape compared to natural sand, resulting in large surface areas that retain more air voids [38].

There is no end on research of glass powder but it mainly effect dosage, workability, alkali silica reactions, porosity, mechanical properties and freeze thaw. Glass powder can be used in small scale project being economical and easily available .Based on above literature review current research focuses on the workability and mechanical properties of concrete. Workability of fresh matrix decides adaption of SCMs and compressive strength decides the load carrying capacity of concrete making it applicable for practical purposes. In this research four mixes were casted in which cement was replaced with waste glass powder from 0%-30% and compression test of specimens was conducted after 3 7 and 28 days respectively.

2. Experimental Procedures

2.1 Raw materials

In this study (1) Ordinary Portland cement (OPC-43, Type-I) (2) locally available sand from Yamuna river having fineness 2.6 (3) coarse aggregate from crushed stones having nominal size 20mm. and (4) Glass powder obtained by crushing waste glasses in loss angles abrasion machine for 20 min and sieved from 150 and 90 µm sieve respectively, were used. Table 1, Table2, Table 3 and Table 4 show details of properties of materials used.

Table 1: Properties of cement

S. No.	Description of Test	Test Results Obtained
1.	Cement used	OPC 43 grade
2.	Specific gravity of cement	3.15
3.	Fineness (Sieve Analysis)	95% passing (90µm)
4.	Standard Consistency	33%

Table 2: Properties of fine aggregate

S. No.	Description of Test	Test Results Obtained
1.	Specific gravity of fine aggregate	2.64
2.	Water absorption of fine aggregate	0.80%
3.	Grading of fine aggregate	Zone – II

Table 3: Properties of Coarse aggregate

S. No.	Description of Test	Test Results Obtained
1.	Specific gravity of coarse aggregate	2.7
2.	Water absorption of coarse aggregate	0.81%
3.	Grading of coarse aggregate	2^{nd} grade
4.	Nominal Size Of Aggregates	20 mm
5.	Aggregate Impact Value	26.33%
6.	Crushing Value	22.56%

Table 4: Properties of glass powder

S. No.	Description of Test	Test Results Obtained
1.	Colour	Grayish White
2.	Fineness (Sieve Analysis Passing 150µm)	99.5 %
3.	Fineness (Sieve Analysis Passing 90µm)	98 %

2.2 Experimental procedure

For compressive strength analysis cubes of size 150mm×150mm×150mm were casted. Casting of all the samples were done at room temperature condition with 25±3ºC. The dry mixing of cement sand and aggregates was done for 1min in mixer, then water was added and mixture was thoroughly mixed in mixer for 8± 2 minutes. The slump was measured with slump cone apparatus. Crushed waste glass powder was added to cement during dry mixing slowly. Cubes were demoulded after 24 hrs and were placed in curing tank with clean water. Curing was done for 3, 7, and 28 days respectively. The compressive strength was obtained in universal testing machine with which load was applied at 5000N/sec as shown in fig 1. Table 5 gives details of percentage of cement replacement while table 6 gives details of mix proportions which were tested after 3, 7, and 28 days respectively.

Figure 1: compression in UTM

Table 5: Percentage of Cement replacement with waste glass powder

Mix I	Conventional concrete with 100% cement (reference sample)
Mix II	10% Waste Glass Powder + 90% Cement
Mix III	20% Waste Glass Powder + 80% Cement
Mix IV	30% Waste Glass Powder + 70% Cement

Table 6: Mix proportions that were tested after 3, 7, and 28 days respectively.

	Cement (kg/m^3)	Glass Powder (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water Content (kg/m^3)
MIX - I	445.530	0	531.560	1194.846	191.58
MIX - II	400.977	44.553	531.560	1194.846	191.58
MIX - III	356.424	89.106	531.560	1194.846	191.58
MIX - IV	311.871	133.659	531.560	1194.846	191.58

3. Result and Discussion

The workability of mixes decreased with the increase in the waste glass powder content, the least value was observed at the higher percentage replacements which are attributed to the slump loss. As flowability of motar decreased because movement of cement paste was hindered due to the algormation of glass particles which resulted in the reduction of the water content in fresh matrix, also geometry of waste glass i.e sharper edges, more angular shape and higher aspect ratio of glass particles reduce the flowability [37]. This can be overcome with the addition of super plasticers, because if more water is added the strength will decrease.

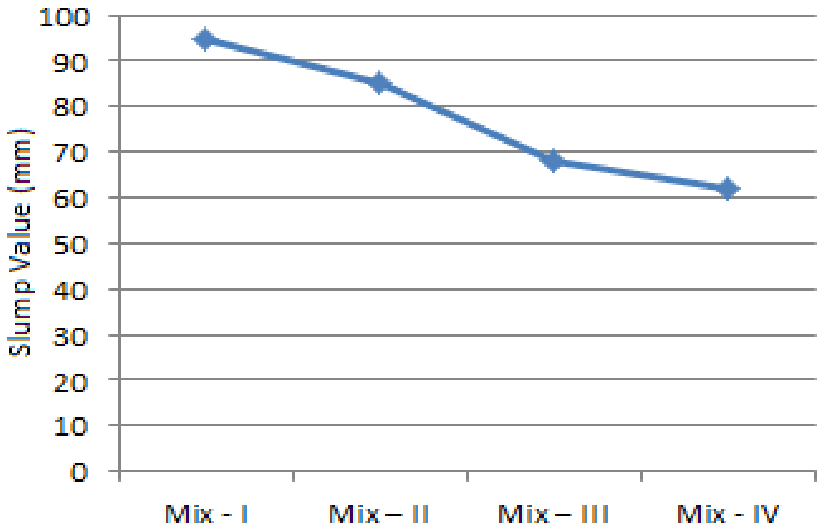

Figure 2: Workability of different mix proportion

With the addition of waste glass powder the total heat generated reduced continuously with the higher percentage of OPC replacement due to the dilution of cement and slow pozolonic reactions. At later stage of hydration process calcium hydroxide (CH) is consumed thus slowing the CSH formation. Since the glass powder is silica rich in nature therefore, the decrement of calcium hydroxide (CH) overcomes [25, 28, 29, 30, 31]. As shown in figure 3, 4, 5 respectively, 20% replacement is the optimum dosage of waste glass powder that can be incorporated in the mix with cement: sand: coarse aggregate= 1:1.19:2.68, and water cement ratio (w/c) = 0.43. It may be due to reduction in alkali silcali reactions expansion with mortar modified at 20% replacements as verified by Kamali at.el [25]. As alkali silcali reactions is attributed to the particle size of waste glass. The glass particles used should have been more finer as the coarser particles get partially dissolved in the hydration process while finer particles get completely consumed by pozolonic reaction even before alkali silica reaction commences[28,31].

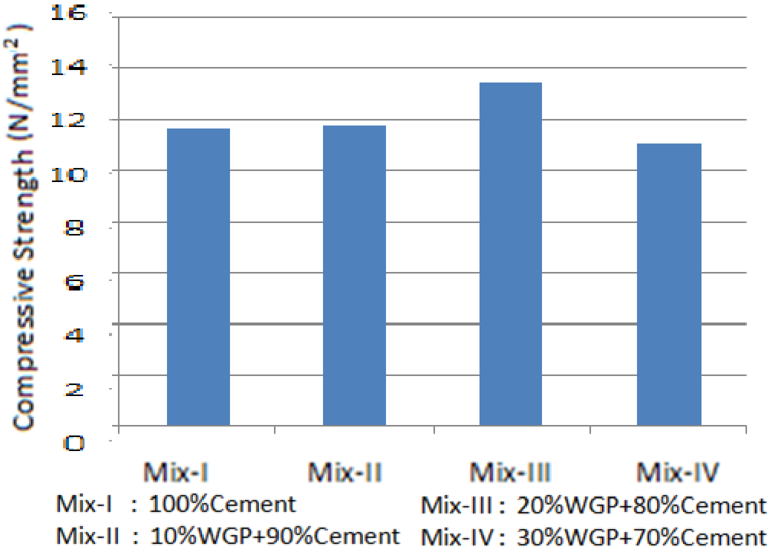

Figure 3: Compressive strength after 3 days

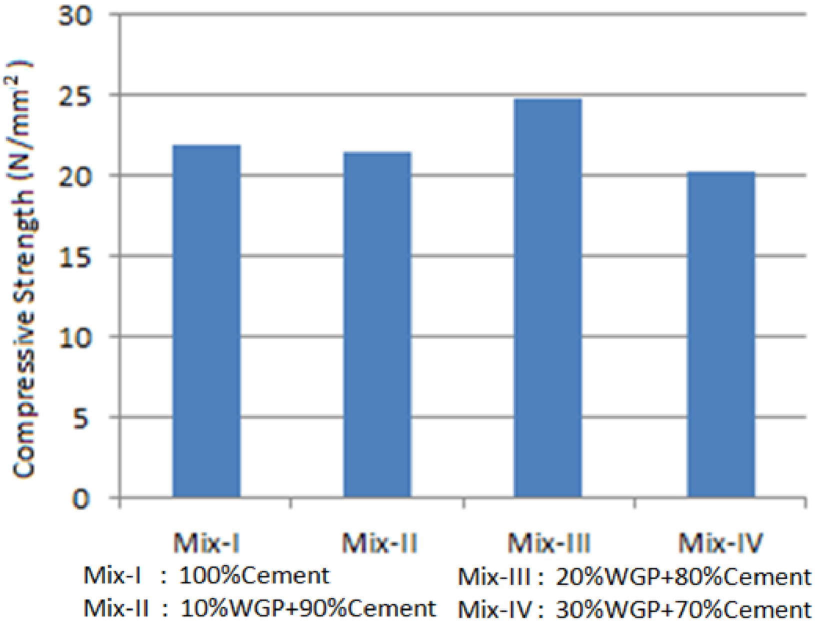

Figure 4: Compressive strength after 7 days

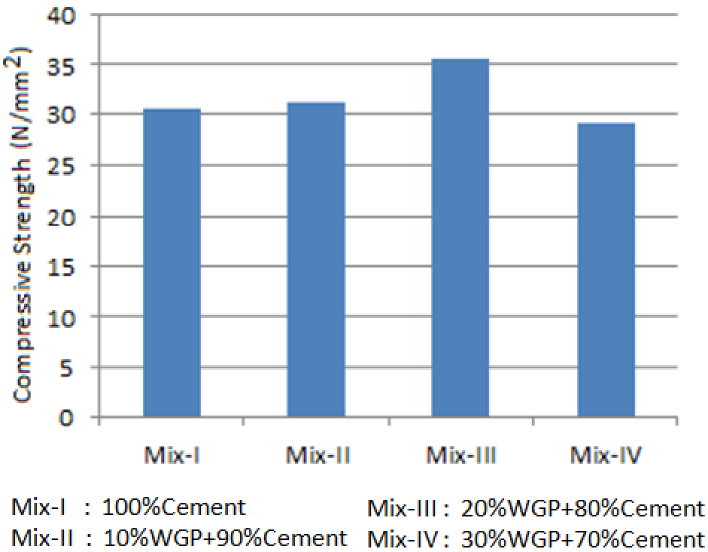

Figure 5: Compressive strength after 28 days

Waste Glass powder finer than 150 micron also acts as filler material there by filling most of the voids between large aggregates in concrete. 20% replacement of cement by waste glass powder raises the pozolanic reaction, as denser CSH gel and less permeable micro structure is formed [15]. The filling effect of submicron size glass particles results in increase of strength than the reference mix proportion 1:1.19:2.68, and water cement ratio (w/c) = 0.43 as shown in figure 6.

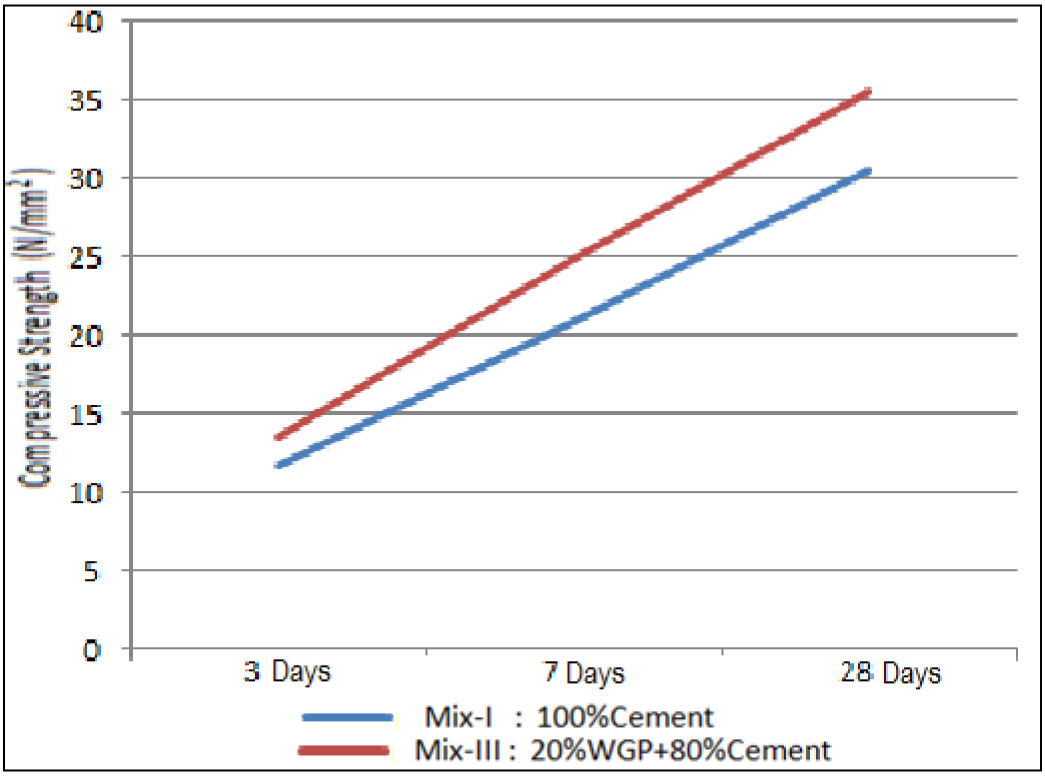

Figure 6: Comparative Compressive Strength between Mix-I & III

4. Conclusion

Based on above experimental results following conclusion can be drawn:

1) Waste glass powder considerably increased compressive strength of mix proportion cement: sand: coarse aggregate= 1:1.19:2.68, and water cement ratio (w/c) = 0.43
2) For all days i.e. 3, 7, 28 days respectively, 20% replacement is optimum as this amount has been verified by many researchers.
3) Porosity reduced due to filler effect of glass powder. Also air voids got reduced.
4) Even though workability reduced but it can be improved by use of plasticizer. This slump flow can be used for self consolidating concrete
5) Setting time accelerated due to high silica and calcium content of glass. This can be used for production of early setting concrete.

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