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Reuse of Wastes in Concrete

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Abstract

The concrete is considered to be the 2nd most abundantly used material in the world after water. Since, its preparation causes rapid environmental degradation. Therefore, efforts are being made for a sustainable development to secure the environment. This study was design to study the usage of locally available waste materials in concrete. The cement was replaced by MWG, sand by waste glass and coarse aggregate by demolished concrete material, at varying proportions. More than 150 cylinders were casted using various ingredients proportionality to study the compressive strength at 7th day, 14th day and 28th day. An additional 60 prisms were also prepared to study the 28 days flexural strength. Using SYSTAT software, the percentage partial replacement of cement, fine and coarse aggregate, for the matrix of green concrete preparation, was calculated to be 9%, 37% and 74%, respectively, with a water-cement ratio of 0.45. The ultimate laboratory analysis of the green concrete, illustrates that its compression and flexural strength is 3-4% more than that of the normal concrete rendering cost saving and reducing environmental impact. The paper besides using various gradation of waste glass as partial replacement of cement and fine aggregate and recycled aggregate as partial replacement of coarse aggregate also used a novel technique of Response Surface Analysis to reach optimum replacement volume fractions.

Keywords: Wastes, environmental preservation, concrete, strength

1 Introduction

The concrete usage started longtime ago, as Romans used it as late as 300. Today, concrete is extensively used construction material worldwide, with an annual production of 5.0 billion cubic yards. The concrete quantity is approximately double of all other construction materials in use (Harald *et al.,* 2014, Arshad *et al.,* 2014). Normally, the cement, sand and aggregate are mixed in definite proportions to form a concrete with the water-cement ratio an important factor which decides the strength of concrete. However, the quality of concrete is evaluated through its compressive and flexural strength, durability, permeability, elastic modulus etc (Bambang, 2014).

Cement is one of its major ingredients, but its production releases excessive amount of CO_2, i.e., 1 ton of CO_2 is released per 1 ton of cement production. The conservation and environmental protection has become a major global issue, especially in context of reducing CO_2 emission on a large scale (James and Masanobu, 2013, Payam *et al.,* 2013). It is estimated that more than 10% of the total world CO_2 comes from the cement manufacturing sources, as more than 1.89 billion ton of cement is produced annually world-wide (Megat *et al.,* 2013, Bisceglie *et al.,* 2014, Sheen *et al.*, 2014). The concept of cleaner technology, give more stress to the reduction of CO_2 emission. That could also be done by means of saving cement, through partial replacement with other similar materials, recycling various cement or concrete materials (Chitnis *et al.,* 2005, Wang and Tan, 2006). And such type of concrete, which does not lead to environmental degradation, is commonly known as green concrete. The green concrete will have less energy intensive while being eco-friendly, economical, with considerably improved mechanical properties, toughness and will preserve the nature as well (Zhang *et al.,* 2008).

The rapid global developments that took place in the past few decades have opened proficient replacement of concrete ingredients with other materials of the similar nature and properties, with considerable strength and durability. Various materials like demolished brick work, concrete debris, fly ash, rice husks, waste wood, plastic chips, broken tiles etc, have been used successful by different researchers to develop green concrete with optimum strength (Aldahdood *et al.,* 2013, Vlastimir *et al*., 2013, Harn and Susmita, 2014, Zhao and Sun, 2014). It not only reduces the burden on natural deposits but also saves us from dumping of waste materials into landfills (Abraham *et al.,* 2014, Chen *et al.,* 2013).

As the green concrete is a revolutionary concept in the history of concrete. Green concrete structures such as bridges, dams, platforms, columns exist today and are practiced in countries where waste disposal systems and its recycling are in order. In Pakistan, the concept has started gaining acceptance and sooner we will see many green concrete structures (Heede and Belie, 2012, Qianqian *et al.,* 2014, Mahdi *et al.,* 2014). Some recent examples are the use of high volumes of fly ash, utilization of micro silica in high rise buildings and manufacturing of cement with reduced environmental impact through use of mineralized performance improvers, waste derived fuel and byproducts as alternate raw materials etc (Corrochano *et al.,* 2013). This study is also inline with the same concept in that different gradation of wastes glass was used as partial replacement of cement and sand, whereas recycled coarse aggregate from concrete debris was used as partial replacement of

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coarse aggregate in concrete. Important engineering properties were evaluated and cost effect analysis was carried out to ascertain the feasibility of optimum replacement through the use of Response Surface Analysis.

2 Material and Methodology

In this study Ordinary Portland Cement (OPC) confirming to ASTM C150 Type-1, Cherat Cement was used. The Initial and Final Setting Times of cement were determined as per IS:4031, using the "Vicat Needle Apparatus" (Arshad *et al.*, 2014). The results are shown in Table 1.

Table 1: Results of Vicats Needle Test

Consistency (%)	**Initial Setting Time (min)**	**Final Setting Time (min)**
31	104	367

The sieve analysis of various ingredients was performed in accordance with the ASTM Standard C136-04. Locally available dry sand of Lawrencepur site, graded between 4.75mm (#4 Sieve) and 150μm (#100 Sieve) was used for all the samples. And the "Margalla Crush" was used with nominal maximum size of ¾ inches. The result of sieve analysis of sand and crush is shown in the Table 2 and Table 3, respectively. The Aggregate Impact Value of 15.48% was calculated as per IS:2386 (Part-4) to measure resistance of aggregate to sudden impact (Harald *et al.*, 2014, Susilorini *et al.*, 2014).

The powder form wastes glass, called the Milled Waste Glass (MWG), obtained from the dump yard of "Gunj Glass Factory, Hasanabdal" was used to replace the cement in concrete. For the replacement of fine aggregate in concrete, a waste glass graded between 4.75mm (#4 Sieve) and 150μm (#100 Sieve) was used (Luca, 2011). And the recycled aggregate of slabs, in the form of previously casted broken concrete cylinders obtained from the concrete testing laboratory, with nominal maximum size of ¾ inches were also used to replace coarse aggregate during this study.

Table 2: Sieve analysis of sand

ASTM Sieve #	**Mass retained (gm)**	**Cumulative mass retained (gm)**	**% Retained**	**Cumulative % Retained**	**% Finer**	**ASTM Range**	**Lower limit**	**Upper limit**
4	1.3	1.3	0.3	0.3	99.7	95-100	95	100
8	16.4	17.7	3.9	4.2	95.8	80-100	80	100
16	64.3	82	15.4	19.7	80.3	50-85	50	85
30	110.8	192.8	26.6	46.3	53.7	25-60	25	60
50	130.3	323.1	31.3	77.6	22.4	10-30	10	30
100	84.5	407.6	20.3	97.8	2.2	2-10	2	10
200	1	408.6	0.2	98.1	1.9	0	0	0
PAN	8	416.6	1.9	100.0	0.0			
Total	416.6					**FM = 2.46**		

Table 3: Sieve analysis of coarse aggregate

ASTM Sieve #	**Mass retained (gm)**	**Cumulative mass retained (gm)**	**% Retained**	**Cumulative % retained**	**% Finer**
1"	0	0	0	0	100
3/4"	42	42	4	4	96
1/2"	421	463	43	47	53
3/8"	292	755	30	77	23
3/16"	214	969	22	99	1
PAN	8	977	1	100	0
Total	977				

The sieve analysis data of MWG and recycled aggregate is shown in Table 4 and Table 5, respectively. The following experimental matrices were prepared using standard procedures (Mesci and Elevli 2012, Salawu *et al.*, 2014).

1. Normal concrete (designate with NC)
2. Cement replacement with MWG (designated with CR)
3. Fine aggregate replacement with waste glass (designated with FAR)
4. Coarse aggregate replacement with recycled aggregate (designated with CAR)

Three 3.0 different trial matrices of a normal concrete were formulated as shown in the Table 6. A constant slump of 2-3 inches was maintained in all the samples for consistency. But the TM-3 (Trial Matrix-3) with highest 28 days strength, i.e. 5075 psi, was selected for the replacements of different concrete ingredients during the study.

As shown in Table 7, the MWG was used in different percentages as a partial replacement of cement in concrete by 5%, 10% and 15%. Whereas, both the fine and course aggregate was replaced by 25%, 50% and 75% with wastes glass and recycled aggregate, respectively (Zhang *et al.*, 2008). Tables 8 and 9, show the ingredient composition of concrete with partial replacement of fine and coarse aggregates.

A total number of 154 cylinders were casted of various ingredients proportions to study the compressive strength of the design concrete at 7, 14 and 28 day. For a 28-days flexural strength test, additional 60 prisms were also prepared for different concrete ingredients proportions.

A response surface analysis was done using SYSTAT software by adopting the canonical analysis, ridge analysis and desirability analysis techniques to determine the final matrix of the "Green Concrete". The 28-days compressive and flexural strengths and the cost of each matrix were used as an input basis for the response surface analysis (Harn and Susmita 2014, Mahdi *et al.*, 2014, Qianqian *et al.*, 2014). Finally, 9 cylinders and 3 prisms of green concrete were casted to study with refined proportions to evaluate their compressive and flexural strengths.

Table 4: Sieve analysis of MWG

ASTM Sieve #	Mass retained gm)	Cumulative mass retainer (gm)	% Retained	Cumulative % retained	% Finer	ASTM Range	Lower limit	Upper limit
4	5	5	1.7	1.7	98.3	95-100	95	100
8	62	67	21.2	22.9	77.1	80-100	80	100
16	41	108	14.0	37.0	63.0	50-85	50	85
30	112	220	38.4	75.3	24.7	25-60	25	60
50	40	260	13.7	89.0	11.0	10-30	10	30
100	30	290	10.3	99.3	0.7	2-10	2	10
200	1	291	0.3	99.7	0.3	0	0	0
PAN	1	292	0.3	100.0	0.0			
Total	292					**FM = 3.25**		

3 Results and Discussion

The Fig 1-3 illustrates the 7, 14 and 28 days compressive strength of various types of concretes used in this study. The compressive strength of NC (Normal Concrete) was observed to be 3236psi, 4685psi and 5075psi on the 7^{th}, 14^{th} and 28^{th} day. As shown in the figures, the results of 75-CAR (76% Coarse Aggregate Replacement) are more than all the samples tested in this study. It might be due to the reason that the recycled aggregates are more compact and denser; therefore, they can provide better compressive strength (Chen *et al.*, 2013, Payam *et al.*, 2014). The 50-CAR was also observed to have more compressive strength than that of the NC during all tests for compressive strength. It was also noticed that the 15-CR (15% Cement Replacement) gives comparatively, minimum compressive strength.

Table 5: Sieve analysis of recycled aggregate

1"	0	0	0	0	100
3/4"	83	83	6	6	94
1/2"	748	831	53	59	41
3/8"	321	1152	23	82	18
3/16"	247	1399	18	99	1
PAN	8	1407	1	100	0
Total	1407				

Though, the compressive strength of 5-CR and 10-CR at 7^{th} and 28^{th} days are observed to be more than that of the NC, but an abrupt decease in the strength was noticed once the ratio of cement replacement was raised from 5-10% to 15%. Though, the 14^{th} day compressive strength of both the samples, i.e., the 5-CR and 10-CR was observed to be less than that of the NC. With respect to 28 days compressive strength it can be extracted that the 5-10% CR with MWG or 50-75% CAR with recycled aggregate can be safely used in concrete, owing to higher strength than that of the NC.

Table 6: Composition of trial matrix

Ingredients	TM-1 (kg/m^3)	TM-2 (kg/m^3)	TM-3 (kg/m^3)
Water	199	199	233.23
Cement	423.4	414.11	519.2
Fine aggregate	667.6	744.6	519.2
Coarse aggregate	1020	944	1038.3
Water/cement ratio	0.47	0.48	0.45
Compressive strength	3101psi	3465psi	5075psi

Table 7: Partial replacement of cement with MWG

Ingredients	**5% (kg/m^3)**	**10% (kg/m^3)**	**15% (kg/m^3)**
Water	233.23	233.23	233.23
Cement	493.24	467.28	441.32
MWG	25.96	51.92	77.88
Fine aggregate	519.2	519.2	519.2
Coarse aggregate	1038.4	1038.4	1038.4
Water/cement ratio	0.45	0.45	0.45

Table 8: Partial replacement of fine aggregate with wastes glass

Ingredients	**25% (kg/m^3)**	**50% (kg/m^3)**	**75% (kg/m^3)**
Water	233.23	233.23	233.23
Cement	519.2	519.2	519.2
Fine aggregate	389.4	259.6	129.8
Waste glass	129.8	259.6	389.4
Coarse aggregate	1038.4	1038.4	1038.4
Water/cement ratio	0.45	0.45	0.45

Table 9: Partial replacement of coarse aggregate with recycled aggregate

Ingredients	**25% (kg/m^3)**	**50% (kg/m^3)**	**75% (kg/m^3)**
Water	233.23	233.23	233.23
Cement	519.2	519.2	519.2
Fine aggregate	519.2	519.2	519.2
Coarse aggregate	778.8	519.2	259.6
Recycled aggregate	259.6	519.2	778.8
Water/cement ratio	0.45	0.45	0.45

The results of 28-days flexural strength are shown in the Fig 4. The flexural strength of NC was observed to be 1029psi; almost same values were obtained for the 5-CR and 25-CAR samples. However, the 28-days flexural strength results of 10-CR was unexpected, i.e., 1205psi. It might be because of the reason that the MWG are stronger than the normal cement in flexural, if used in concrete to certain proportionality only. Contrary, the 15-CR shows comparatively a weak response to flexural, as its strength was observed to be 920psi.

The 28-days flexural strength of 25-FAR, 50-FAR and 75-FAR samples was noticed to be 943psi, 999psi and 903psi, respectively. Whereas, the 10-CR 50-CAR and 75-CAR show better results than that of the NC, i.e. 1205psi, 1100psi and 1346psi, respectively. The 2-days flexural strength of 75-CAR is 24% more than that of the NC. As mentioned earlier, the recycle aggregate are relatively more compact, therefore, they can safely replaced with the coarse aggregate. Figure 1-4 confirms the better compression and flexural strength of the coarse aggregate replacement with recycled aggregate. Fig 1-4 also provides guidelines for the usage of various concrete ingredients replacement to achieve economical and safe desired strength results.

Table 10 and 11, shows the results of response surface analysis using SYSTAT and the calculated final composition of matrix for the green concrete (Harald *et al.*, 2014, Yu *et al.*, 2014). The designed percentage replacement of cement, fine aggregate and the coarse aggregate was calculated to be 9%, 37% and 74%, respectively. Finally, as computed, 233.2kg of water, 472.5kg of cement, 46.7kg of MWG, 327.1kg of fine aggregate, 270kg of coarse aggregate and 768.4kg of recycle aggregate is required for the preparation of one cubic meter of green concrete, with a water-cement ratio of 0.45.

Table 10: Results of SYSTAT

Factors	**Optimum responses**
Cement = 9%	28-Compressive strength = 7790psi
Fine aggregate = 37%	28-Flexural strength = 1598psi
Coarse aggregate = 74%	Cost = 43USD/m^3

Table 11: Final matrix of the Green Concrete (kg/m^3)

Water	233.2
Cement	472.5
MWG	46.7
Fine aggregate	327.1
Coarse aggregate	270.0
Recycled aggregate	768.4
Water/cement ratio	0.45

Refer to Fig 5, the 7-days, 14-days and 28-days compressive strength of green concrete was observed as 3317psi, 4322psi and 5326psi, respectively. While its 28-days flexural strength was noticed to be 1065psi. Fig 6 illustrates the strength comparison of green concrete with that of the normal concrete. As shown, the compressive and flexural strength of the green concrete was observed to be more by 3-4% than that of the normal concrete. Thus, the design green concrete is comparatively better both in the compression and flexural, with relatively minimal cost.

4 Conclusions and Recommendations

Though with a minor drawbacks, as the particles size of recycled aggregate are more cementitious that increases the water absorption ratio, which gives rise to the attachment of greater amount of mortar paste to the surface of recycled aggregate particles, and ultimately causes more shrinkage on drying. Similarly, if the size of glass particle is slightly larger, it can give rise to alkali silica reaction that can reduce the strength. But still the usage of various types of wastes is cost-effective for concrete, without compromising on its quality. Moreover, if the size of MWG is less than 100µm, then it can acts as a pozzolanic material, overcoming the drawbacks caused by the alkali silica reactions. It is also concluded that the recycled aggregate and MWG when used together forms an improved interfacial transition zone.

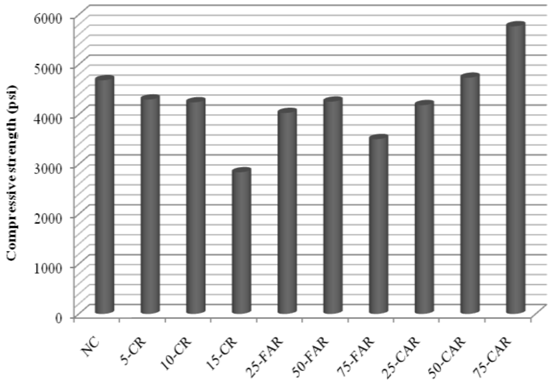

Fig. 2. 14-Days compressive strength of various types of concrete used in the study (NC = Normal concrete, 5,10,15-CR = Percentage cement replacement, 25,50,75-FAR/CAR = Percentage fine/coarse aggregate replacement)

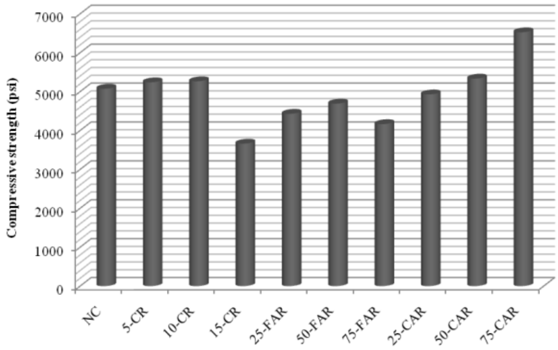

Fig. 3: 28-Days compressive strength of various types of concrete used in the study (NC = Normal concrete, 5,10,15-CR = Percentage cement replacement, 25,50,75-FAR/CAR = Percentage fine/coarse aggregate replacement)

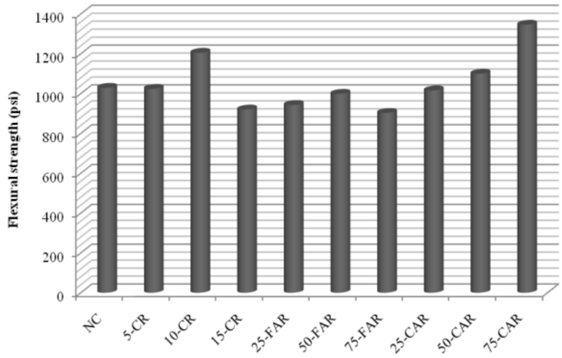

Fig. 4: 28-Days flexural strength of various types of concrete used in the study (NC = Normal concrete, 5,10,15-CR = Percentage cement replacement, 25,50,75-FAR/CAR = Percentage fine/coarse aggregate replacement)

Furthermore, the production of glass particles and glass powder by crushing requires far less effort and energy as compared to the production of other pozzolanic materials. And the cheaply available recycled aggregate can be easily obtained from any demolished site and can be converted to suitable size by using portable crushers. Such practices will reduce the burden on natural deposits, making this world Green.

However, further investigations on green concrete for long term strength are recommended. And the environmental and casting factors need to be incorporated during advance studies on the same subject.

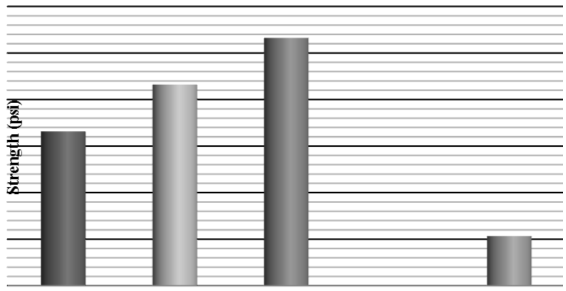

Fig. 5: Compressive and flexural strength of Green Concrete

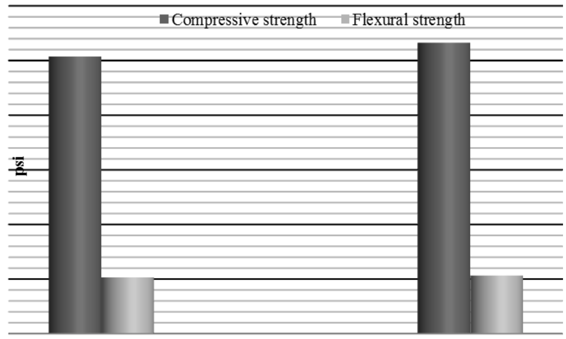

Fig. 6: Strength comparison of normal concrete and green concrete

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