Investigation of Properties of Concrete Containing Recycled Concrete Coarse Aggregate and Waste Glass Powder

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Abstract. The construction industry in Ethiopia is booming with a resulting increase in requirement of cement concrete as an input. The industry faced with depletion of natural aggregate, increasing the scarcity of landfills, haulage and landfill costs. The environmental and economic concern is not limited to concrete wastes but it also includes non-degradable wastes originating from materials like waste glass. In this study, recycled concrete aggregate (RCA) produced from a demolished concrete structure and waste glass powder (WGP) sourced from end-life and broken glass containers and bottles are used. A detailed experimental analysis is conducted to assess the workability and compressive strength of recycled aggregate concrete (RAC) made with partial replacement of natural aggregate (NA) and cement by recycled concrete aggregate (RCA) and waste glass powder (WGP) respectively. A concrete mix prepared with 0%, 25%, 50%, and 75% replacement of NA by RCA and 0%, 10% and 20% partial replacement of cement by WGP in each RAC mixes. The result shows that the waste glass powder replaced recycled aggregate concrete shows better workability and compressive strength development than the recycled aggregate concrete mix without waste glass powder and comparable with the control mix. The waste glass powder (WGP) as a partial replacement of cement can overcome the limitations of recycled concrete aggregate and paving the way for its broadly used in recycled aggregate concrete (RAC) production. The outcomes of this research would assist the growing construction industry to be sustainable thereby reducing waste and conserving the natural resource.

Keywords: Recycled concrete aggregate (RCA) · Recycled aggregate concrete (RAC) · Waste glass powder (WGP) · Workability · Compressive strength

1 Introduction

The growth in industrialization and urbanization of a country could manifested by the level of construction activities including buildings, roadways, and bridges. The construction industry should continue to meet the demand of the growing population of

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one country, which as a result needs a huge amount of construction materials such as concrete. One of the most widely and extensively used construction materials in almost all conceivable construction activities is cement concrete.

Cement concrete is composed of Portland cement, fine aggregate, coarse aggregate, water, pozzolans, and admixture. It creates two major negative impacts on the environment within the Globe. On one hand, the production of concrete consumes large amounts of Natural Aggregate (NA). For instance, the concrete industry in the world demands more than 10 billion tons of natural aggregate (NA) every year, and this demand will doubled in the next 20 to 30 years [1]. On the other hand, concrete waste will be produce due to reconstruction, demolition, and renovation, which creates a large amount of C&D waste.

Currently, the concrete industry in the world not only have been making use of industrial wastes like fly ash, silica fume, and blast furnace slag as pozzolans but also waste glass powder is partially replacing cement [2]. Million tons of waste glass generated annually all over the world [3]. For example, the total global waste glass production was estimate 130 Mt, in which Europe, China, and the USA produced approximately 33 Mt, 32 Mt, and 20 Mt, respectively [3]. In Egypt, about 3.45 Mt of waste glass produced per annum and 84% of which is lifted to landfills [4].

Even in developing nations, these huge glass wastes given less attention to use for application purpose [5]. Current studies also show that most developing countries are facing a shortage of consumers' disposal waste site [5]. Considering the consumers' waste glass, there is no full effort to recover rather end up at disposal landfill or stockpiling in a huge mass. According to IGNIS [6] Joint project report, in Addis Ababa; the total annual glass waste is 5843t that covers 2.4% of the total waste, only 977t glass is recovered and the remaining thrown to landfill. Here, recovery and recycling mechanism in Ethiopia is minor.

Recycling of aggregate is not limited to new concrete production rather it also used as a raw material for pipe bedding, landscape materials, and as base course material for road construction [7]. Additionally, in recent studies using recycled concrete aggregate (RCA) for concrete production have shown that there could be a reduction of fuel consumption and dumping cost, as natural aggregate consumes a considerable amount of energy at each step of the production process [8]. Considering this precedent, the economic advantage of recycling in Ethiopia is to overcome a limited land for a wastage disposal site [9]. Here, the author does not show the improvement methods of RAC and usage of pozzolanic material like WGP. On the other way, different researchers tried to improve the quality of recycled concrete aggregates by using chemical treatment method, mechanical action and using pozzolans to increase the hardened properties of RAC [10].

According to F.Nosouhian and D.Mostofinejad [11], show the potential usage of Waste Glass Powder and the workability of recycled aggregate concrete is slightly increase with the addition of Waste Glass Powder. For fresh state of concrete Nasser [12], reveals that the workability increased by 9 mm when cement replaced by 20% with waste glass powder and natural aggregate replaced by 50% with RCA by weight. Waste glass powder with 20% by weight of cement results in good improvement of the structure of hydrated cement paste in RAC. On the contrary, the use of glass powder as cement replacement decreases concrete workability. Approximately, each 5.0% glass powder addition decreases the slump value by 10 mm in RAC [13]. This trend may be due to the increase of fine material content, which increases the cohesion of the concrete mix and thus decreases the concrete slump.

For harden properties of concrete, WGP have a positive effect on RAC, which undergo pozzolanic reactions with cement hydrates (adhered mortar), forming secondary calcium silicate hydrate (C–S–H) since it contains silicate compounds in a large amount [14]. The compressive strength of RAC containing 50% RA and 20% WGP as partial replacement of cement is comparable with conventional concrete [15]. Moreover, there is an improvement in concrete compressive strength is observed up to 10.0% glass powder cement replacement and 50% RCA content [13]. On the other contrary, a test conducted by R. Nassar and P. Soroushian [12], conclude that the 28-day compressive strength of RAC containing 20% waste glass powder and 50% recycled aggregate shows a decrease in strength.

The previous behavior of RAC concrete containing WGP is somehow contradict with different researchers' discussion and now the compressive strength and workability is observed too. The limits of practicing of WGP as a pozzolanic material in RAC is investigate in new concrete production and its contribution towards sustainable concrete production in the Ethiopian construction industry.

2 Materials and Methods

The research focuses on recycling demolition concrete wastes from demolished buildings, which exist in the city of Bahir Dar, Ethiopia. The sample taken is included only concrete wastes that were produce from a demolished concrete structure like column, beams, and slabs. In addition, the waste glass was source from the end-life and broken glass containers and bottles.

2.1 Material Preparation

Ordinary Portland cement (OPC) 42.5R grade, which is available in the local market, is used. This cement is equivalent to ASTM type I. Well-graded crushed basaltic stone collected in quarry sites located around Bahir Dar area were use in this study. The recycled concrete coarse aggregate were collect from existing demolition building structures that exist in Bahir Dar. After all, jaw crusher around Bahir Dar has crushed the collected demolition waste. Locally available river sand used as a fine aggregate for the investigation. For assuring requirements of aggregates, all aggregates tested based on different test methods of ASTM standards. Tables 1, 2 and 3 show the physical properties of recycled concrete coarse aggregate, natural coarse aggregate and river sand; respectively. In addition, Waste Glass used for this study is collected at Bahir Dar town. The waste glass collected from end-life and broken glass containers and bottles. WGP were produce after grinding waste glass with crasher and after all, it allowed passing in a 75-µm ASTM sieve. Figure 1 shows the preparation of waste glass powder.

(a) Waste Glass before crushing (b) Small sized Glass Culets (c) WGP after crushing

Fig. 1. Waste glass powder preparation

Table 1. Physical properties of recycled concrete coarse aggregate

Type of test	Test method	Test result	ASTM requirement
Unit weight	ASTM C29 [16]	1540 kg/m^3	1280 to 1920 kg/m^3
Specific gravity	ASTM C127 [17]	2.6	2.4 to 3.0
Absorption capacity	ASTM C127 [17]	3.3%	0.2% to 4%
Moisture content	ASTM C566 [18]	1.8%	–

Table 2. Physical properties of natural coarse aggregate

Type of test	Test method	Test result	ASTM requirement
Unit weight	ASTM C29 [16]	1640 kg/m^3	1280 to 1920 kg/m^3
Specific gravity	ASTM C127 [17]	2.7	2.4 to 3.0
Absorption capacity	ASTM C127 [17]	1.85%	0.2% to 4%
Moisture content	ASTM C566 [18]	1.01%	–

Table 3. Physical properties of fine aggregates (river sand)

Type of test	Test method	Test result	ASTM requirement
Fineness modules	ASTM C136 [19]	2.9	2.3 to 3.1
Unit weight	ASTM C29 [16]	1710 kg/m^3	1280 to 1920 kg/m^3
Specific gravity	ASTM C128 [20]	2.7	2.4 to 3.0
Absorption capacity	ASTM C128 [20]	2.5%	0.2% to 2.5%
Moisture content	ASTM C566 [18]	1.6%	–

2.2 Chemical Test

Before using Waste Glass Powder (WGP) for concrete application, determining the mineralogical composition of it was essential. The chemical analysis of WGP was determined using Analytical method. After all, the chemical composition test results checked that whether or not conforms to ASTM C618 chemical test requirement. The chemical properties of WGP shown in Table 4.

Table 4. The chemical analysis of waste glass powder and other reference pozzolans

Chemical composition	Results (mass %)	ASTM C 618 limits [21]		
		Class N	Class F	Class C
Silicon Oxide (SiO_2)	75.56	–	–	–
Aluminum oxide (Al_2O_3)	1.38	–	–	–
Iron Oxide (Fe_2O_3)	0.66	–	–	–
Sum of ($SiO_2 + Al_2O_3 + Fe_2O_3$)	77.6	70 min	70 min	50 min
Sulfur trioxide (SO3)	< 0.01	4 max	5 max	5 max
Calcium Oxide (CaO)	9.14	–	$<$10%	$>$10%
Magnesium Oxide (MgO)	0.48	–	–	–
Sodium Oxide (Na_20)	12.06	–	–	–
Potassium Oxide (K_2O)	0.5	–	–	–
Moisture content (H_2O)	0.2	3 max	3 max	3 max
Loss on Ignition (LI)	0.52	10 max	6 max	6 max

2.3 Mix Proportion of Concrete Mixes

The mix design were performed for C-25 grade concrete with targeted workability of 25-50mm as per ACI 211.1. The RCA replacement in coarse NA and partial cement replacement with WGP were varied with 0–75% and 0–20%; respectively. For all mixture's w/c ratio was constant and it was 0.49. Mix proportioning of RAC is shown in Table 5.

2.4 Concrete Casting and Curing

All ingredients of concrete mixes measured by weight in accordance with their proportion and mixture series. Based on the mixture series; all ingredients are added to a mixer and dry mixture was applied. After dry mixing, water added gradually and the concrete mixed uniformly. Once the concrete mixed uniformly, the workability of concrete tested with a slump cone. After all, 15 × 15 × 15 cm cubical samples casted verywell. The samples immersed in a curing tank until the data recorded. All tests carried out according to the provision of relevant ASTM standards.

2.5 Compressive Strength Testing

The compressive strength of 15 * 15 * 15 cm cubes was done on 3rd, 7th, 28th & 56th days after casting depending on ASTM C 109. For compressive strength test, ELE test machine is used. After all, after removing the water on the surface of the concrete, the cubes were tested.

2.6 Data Analysis of Test Results

As an analysis tool for compressive strength test on hardened concrete, simple Microsoft Excel is used.

3 Results and Discussions

3.1 Workability of Concrete Mixes

Table 5 shows the workability of different recycled aggregate concrete mixes without and with waste glass powder having a constant w/c ratio of 0.49. With the same w/c ratio, as the replacement proportion of RCA with NA increases the workability decreases. This is due to the recycled concrete coarse aggregate has higher absorption capacity than natural one; since the recycled coarse concrete aggregate has clinging mortar at the surface. The decrease in workability of concrete containing RCA is attributed to the higher absorption capacity, the rougher surfaces and more irregular shapes of it [22].

Table 5. Mix proportion of different concrete mixes

Mix designation	% RCA	% WGP	Weight of material in Kg/m^3						Total (Kg/m^3)	Slump (mm)
			Cement	WGP	Water	NA	RCA	Sand		
[a] 0RA0WG	0	0	360	0	195.2	1090	0	800	2445	40
[b]0RA10WG		10	324	36	195.1	1090	0	792.5	2438	45
[c]0RA20WG		20	288	72	195	1090	0	787	2433	55
25RA0WG	25	0	360	0	196.3	817.5	258.8	806.3	2438	35
25RA10WG		10	324	36	196.3	817.5	258.8	798.8	2432	40
25RA20WG		20	288	72	196.3	817.5	258.8	793.5	2426.7	48
50RA0WG	50	0	360	0	198	545	517.5	812.5	2431.5	25
50RA10WG		10	324	36	197.5	545	517.5	805.3	2425.5	36
50RA20WG		20	288	72	197	545	517.5	800	2420	43
75RA0WG	75	0	360	0	199.5	272.5	776.3	818.8	2425	20

(*continued*)

Table 5. (*continued*)

Mix designation	% RCA	% WGP	Weight of material in Kg/m^3						Total (Kg/m^3)	Slump (mm)
			Cement	WGP	Water	NA	RCA	Sand		
75RA10WG		10	324	36	199	272.5	776.3	811.6	2419	30
75RA20WG		20	288	72	198.8	272.5	776.3	806.5	2414	40

[a]Control mix.
[b]Counterpart mix that used as a reference for all 10%WGP RAC mixes.
[c]Counterpart mix that used as a reference for all 20% WGP RAC mixes.

On the other hand, with the same w/c ratio and constant partial replacement of cement by waste glass powder, as the replacement proportion of natural coarse aggregate by recycled aggregate increases the workability decreases. However, RAC having WGP has greater workability than RAC without WGP incorporation. This is due to the lower water absorption capacity of WGP than cement. For instance, the workability of RAC mix of 25RA10WG having 10% WGP was greater than the RAC mix of 25RA0WG without waste glass powder by 5 mm slump. To support this argument, the effect was attributed to the relatively low moisture absorption of waste glass powder when compared with cement [12].

3.2 Compressive Strength

Figure 2 shows the compressive strength test results at different concrete ages with similar w/c ratio mixes produced with various percentage of RCA replacing NA, without waste glass powder.

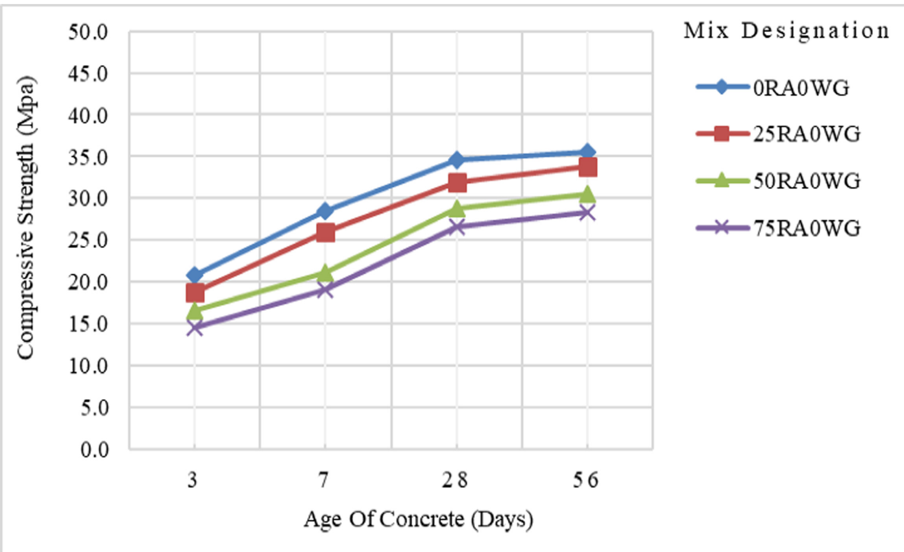

Fig. 2. Compressive Strength of RAC without WGP at Different Ages

Figures 3 and 4 depict that the compressive strength test results of the corresponding RAC mixes containing 10% and 20% partial cement replacement with WGP, respectively. From the RAC mixes without WGP and similar w/c ratio, the compressive strength depends on the proportion of RCA. Its strength decreases with an increased proportion of RCA. Strength development of RAC mixes containing 25% RCA is comparable with the control mix. However, the control mix (0RA0WG) strength development is significant than other RAC mixes. This is due to RCA contains the weak clinging mortar on its surface.

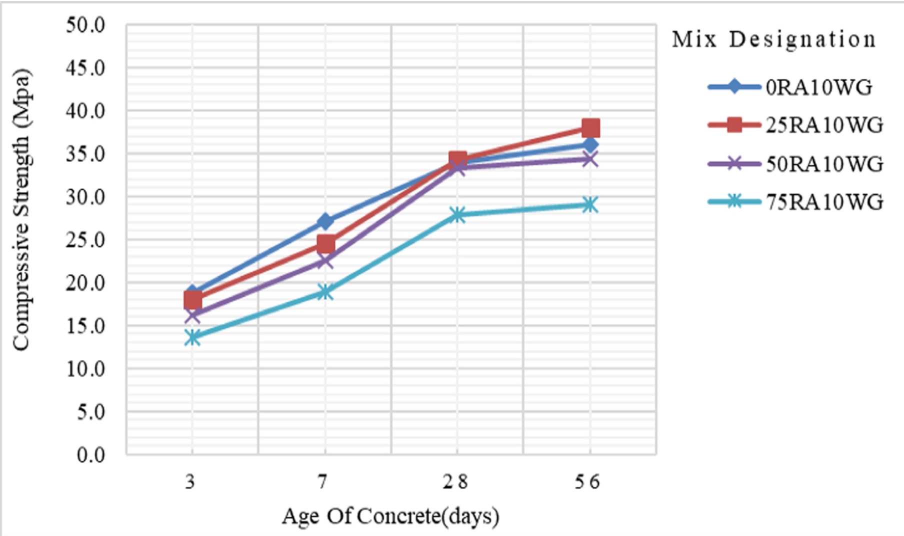

Fig. 3. Compressive Strength of RAC with 10% WGP at Different Ages

Among the RAC mixes containing 10% WGP (Fig. 5), the compressive strength of counterpart concrete mix (0RA10WG) is greater than those of the corresponding RAC mixes containing 10% WGP until 28^{th}-days of ages. After 28^{th}-days of the age of RAC, this trend was not continued due to the WGP benefited the compressive strength development. The statistical analysis of test results indicated the significant benefits of WGP as a partial replacement of cement in RAC mixes with an increase in age of concrete. Here, RAC made with incorporation of WGP show a good strength development as the curing age increases up to 56^{th}-days; where at the 56^{th}-day, 25RA10WG concrete mix is 6% and 7% higher than the counterpart mix (0RA10WG) and the control mix (0RA0WG), respectively. In addition, a 25RA10WG RAC concrete mix is 11% higher than the counterpart mixes of 25RA0WG. Similarly, the strength of the RAC mix of 50RA10WG is 3.3% and 2% lower than the counterpart mix (0RA10WG) and control mix (0RA0WG) at 56^{th}-days, respectively. Furthermore, a 50RA10WG RAC mix increased the 28^{th}-day strength by 14% from that of 50RA0WG RAC mix. This strength development is comparable with the control mix and shows an insignificant difference. This is why the WGP has a positive effect on RAC.

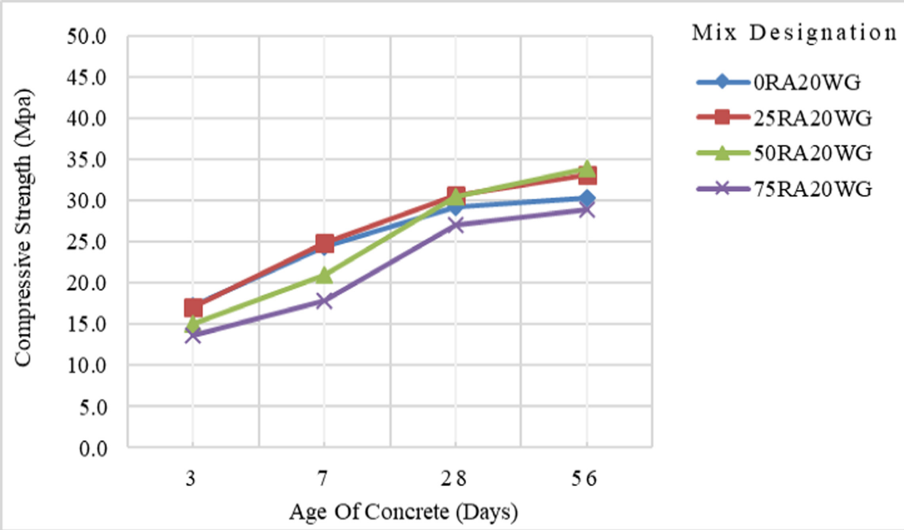

Fig. 4. Compressive Strength of RAC with 20% WGP at Different Ages

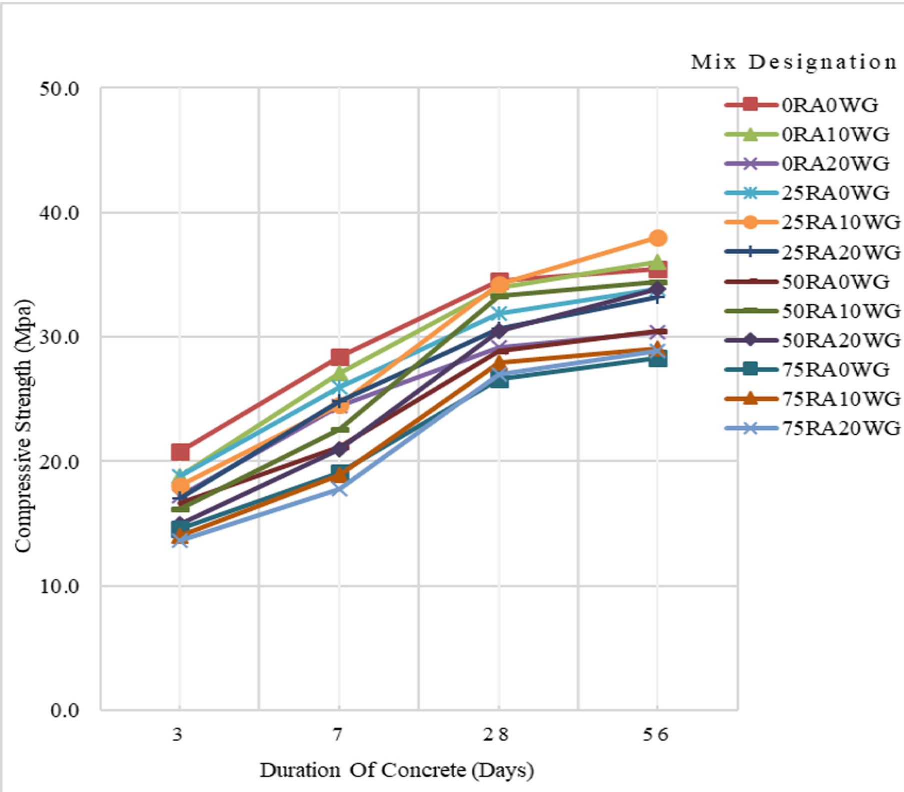

Fig. 5. Overall Strength of RAC Containing Different Percentages of WGP and Ages

The compressive strength test results for RAC mixes containing 20%WGP (Fig. 4) follows trends similar to those for RAC mixes containing 10%WGP. RCA concretes made with WGP replacement continue their strength development up to the 56th-day. The strength development of concrete mixes of 25RA20WG and 50RA20WG are significant at later ages of concrete curing. However, the increase in compressive strength is not significant like the strength of RAC mixes containing 10% WGP.

According to the result, the recycled aggregate concrete containing 25%RCA and 10%WG show a better marginal means for more than 28th-day strength. A recycled aggregate concrete containing 50%RCA and 10% WG also show comparable marginal means for more than the 28th-day strength development.

Therefore, the significant improvement in strength after 28th days of ages is an indirect measure of the pozzolanic reaction between adhered mortar at the RCA surface and the silicate compounds in the WGP. This reaction creates additional cement paste (secondary C-S-H: calcium hydrate silicate) which helps for strength development. This beneficial effect of WGP also observed by earlier researchers who studied the effects of WGP in RAC production [12]. Therefore, this reveals that WGP continues the strength development at a later day as long as there is a favourable amount of temperature and moisture.

4 Conclusion

This study investigated the potential of using waste glass powder (WGP) and recycled concrete coarse aggregate (RCA) in new concrete production. The use of waste glass powder (WGP) as a partial replacement for cement is estimated to effectively overcome the limitations of RCA (higher water absorption and the weakness due to clinging mortar) paving the way for its broadly use towards the production of RAC. Based on the results of this study, the following conclusion was drawn:

- The oxide composition of waste glass powder (WGP) conforms to the requirement of class F pozzolans as specified in ASTM C 618.
- RAC containing WGP have good fresh and hardened properties. The workability of RAC decreases with an increase in the proportion of RCA by weight of natural aggregates but it can improved by incorporating WGP through a partial replacement by weight of cement. The strength of RAC without WGP decreased with an increase in the proportion of RCA. However, the strength of RAC can improved with the incorporation of WGP.
- The replacement of WGP up to 10% enhance the compressive strength of RAC which comprises up to 50% RCA replacement and comparable with the strength of concrete made with natural aggregate and without waste glass powder. However, a further increase in RAC and WGP results a decreased in strength.
- The significant increases in later age strength of recycled aggregate concrete containing waste glass powder achieved through the conversion of calcium hydroxide (CH) into Calcium-Hydrate-Silicate (C-S-H) gel available in the adhered mortar to the surface of recycled concrete aggregate. Therefore, in RAC WGP continues strength development at a later age as long as there is a favourable amount of temperature and moisture.

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