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Experimental Studies on Green Concrete using Volcanic Ash and PVA/VE

Sari W. Abusharar*

College of Applied Engineering and Urban Planning, University of Palestine, PO Box 1075, Gaza, Palestine

* E-mail of the corresponding author: s.abusharar@hotmail.com

Abstract

This paper investigates the influence of volcanic ash (VA) and vinyl acetate/ethylene copolymer powder (PVA/VE) as partial cement replacement on the engineering properties of blended binders concretes. The parameters studied included density, workability and compressive strength. A total number of 12 trial mixtures were prepared and tested by varying the proportions of binders. Firstly, VA was used to replace OPC at dosage levels of 5%, 10%, 15%, 20%, 25%, and 50% by weight of the binder. Secondly, PVA/VE was used to replace OPC at dosage levels of 0.5%, 1%, 1.5%, 2% and 2.50% by weight of the binder. Finally, the optimum replacement levels of VA and PVA/VE were determined and used to prepare a new trial mix. The results show that cement replacement up to 15% volcanic ash and 1.5% PVE/VE leads to increase in workability and compressive strength for C30 grade compared with the control mixture.

Keywords: Green concrete, Compressive strength, Workability, Volcanic ash, PVA/VE

1. Introduction

Concrete is still the most widely used building material and the second most consumed substance on earth after water. In fact, global concrete consumption is estimated to be nearly twice that of all other building materials. The extensive use of concrete stems from its availability, versatility, effectiveness, performance, and economy as compared to alternative building materials. However, the production of portland cement, an essential constituent of concrete, leads to the release of significant amount of CO_2 which identified as a major contributor to the phenomenon of global warming and ocean acidification (Williamson and Turley, 2012; Gattuso & Hansson, 2011; Vaughan and Lenton, 2011; Huntzinger and Eatmon, 2009; Naik, 2008; Hall-Spencer et al., 2008; Bremner, 2001).

The U.S. Geological Survey (USGS) estimated that approximately 7 billion tons of the world total hydraulic cement was produced in 2013 (U.S. Geological Survey, 2014). It is well known that the production of each ton of portland cement clinker is accompanied by the release of approximately one ton of carbon dioxide and other greenhouse gases (GHGs) into the atmosphere (Estakhri and Saylak, 2004; Van Oss and Padovani 2002). The cement production accounts for almost 7% of the total world CO_2 emissions (Ghiasvand et al., 2014; Ali et al., 2011; Naik, 2008; Naik and Moriconi, 2005; Malhotra, 1999; Mehta, 1999). About half of the CO_2 emissions are due to the calcination of limestone and the other half are due to the combustion of fossil fuels. The emissions from the calcination of limestone are fairly constant at about 0.54 tons of CO_2 per ton of cement; the emissions from the combustion depend on the carbon content of the fuels being used and the fuel efficiency (Malhotra, 2008).

The CO_2 emissions associated with the manufacturing of portland cement can be reduced significantly by reducing the production of current clinker (Thomas et al., 2010a; Thomas et al., 2010b; Mehta, 1998). The resulting loss in portland cement production can be overcome by the increased use of environmentally friendly supplementary cementing materials (SCMs) such as fly ash, slag, silica fume, and natural pozzolans (Chanu and Devi, 2013; Owaid et al., 2012; Arredondo-Rea et al., 2012; Thomas et al., 2010b; Vessalas et al., 2008).

VA consists of fragments of pulverized rock, minerals and volcanic glass, created during volcanic eruptions, less than 2 mm in diameter (Rose and Durant, 2009). When VA blended with cement for use in concrete, VA can enhance the strength and durability of hardened concrete. Furthermore, VA contributes several important environmental and economic benefits (Owaid et al., 2012). VA can reduce the needs for cement clinker, the principle binding agent in concrete and the primary source of GHGs emissions in the cement-concrete supply chain. VA can increase the quantity of cementitious material in the marketplace, which expands the potential supply chain for concrete. Finally, given that many VA are waste byproducts, VA usage can reduce landfill requirements and the associated environmental impacts.

PVA/VE is a water-redispersible vinyl acetate/ethylene copolymer powder that exhibits very good resistance to saponification which means it can be used as water reduction plasticizer. Because of its relatively high ethylene content, this resin is soft and flexible. Its glass transition temperature is below freezing point. PVA/VE improves the adhesion, flexural strength, plasticity, abrasion resistance and workability of modified compounds without appreciably affecting flow, thixotropy or water retention. It is therefore compatible with mortar additives used to achieve special processing characteristics. If used in sufficient amounts, PVA/VE impedes the penetration of water. PVA/VE contains fine, mineral filler as anti blocking agent. It is free of solvents, plasticizers and film-forming aids.

This paper presents the results of an experimental investigation studying the behavior of concrete produced from blending cement with VA and PVA/VE as partial replacement for cement. The physical and chemical properties of VA, PVA/VE and OPC were first investigated. The effect of VA and PVA/VE on concrete properties was studied. The optimum mix design with regards to the amount of water, VA, PVA/VE and cement ratio were found.

2. Methodology

2.1 Preliminary Investigations

For the preliminary investigations, materials used in the current study were subjected to physical and chemical analyses to determine whether they are in compliance with the standard used.

2.1.1 Cement

Ordinary Portland cement, Type I, which conforms to ASTM C150-1992, was used in this research with a specific gravity of 3.15. Initial and final setting time of the cement was 50 min and 365 min, respectively. The chemical composition of OPC is given in Table 1.

Table 1. Chemical compositions of OPC and VA.

Element	Composition by weight (%)	
	OPC	VA
SiO_2	19.71	39.64
Al_2O_3	5.20	11.18
Fe_2O_3	3.73	12.92
CaO	62.91	10.43
MgO	2.54	18.79
SO_3	2.72	1.02
K_2O	0.90	1.64
Na_2O_3	0.25	0.95
Loss on ignition (LOI)	0.96	2.96
$SiO_2+Al_2O_3+Fe_2O_3$	28.64	63.74

2.1.2 Volcanic ash

The volcanic ash used was grinded and sieved with a 75 µm sieve. Specific gravity and bulk density of VA were 3.05 and 1649 Kg/m3 respectively. The chemical composition of VA is given in Table 1.

2.1.3 Water

Potable water with pH value of 7.0 was used for making concrete and curing the specimen as well. The water was free of acids, organic matter, suspended solids, alkalis and impurities which when present may have adverse effect on the strength of concrete.

2.1.4 Aggregates

Locally available natural sand with 420 µm maximum size was used as fine aggregate, having specific gravity and absorption of 2.58 and 0.35% respectively. Three types of crushed stones with 19 mm maximum size were used as coarse aggregate, having specific gravity and absorption of 2.65 and 1.6% respectively. These aggregate types are locally known by Foliya, Adasia and Simsymia. The results of the sieve analysis according to ASTM C136-06 for fine and coarse aggregates are presented in Figures 1 and 2 respectively.

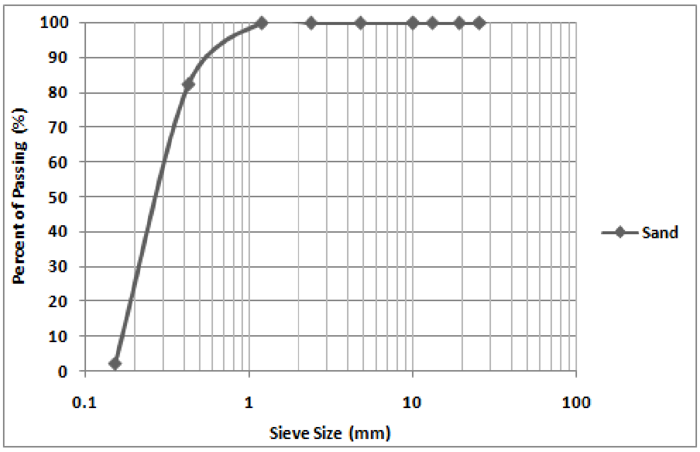

Figure 1. Sieve analysis of fine aggregate

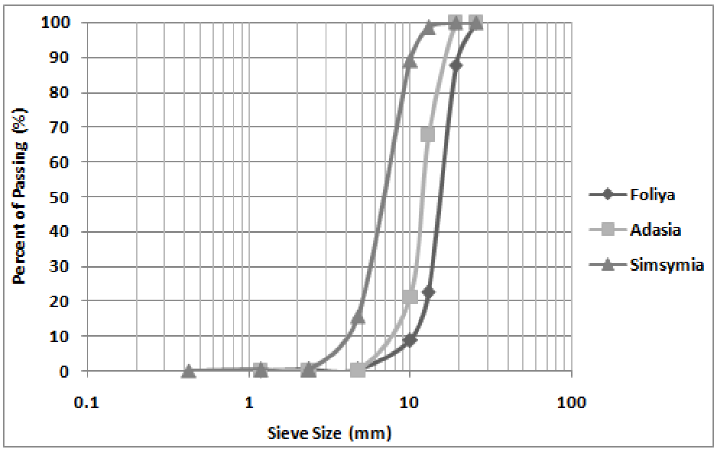

Figure 2. Sieve analysis of coarse aggregate

2.1.5 PVA/VE

PVA/VE is a water-redispersible, solvent-free, plasticizer-free and film-forming aid-free vinyl acetate/ethylene copolymer powder. It is used for blending with inorganic binders, such as cement, anhydrite, gypsum and hydrated lime, in the production of construction and tiles adhesives, in powdery adhesives for external insulation and finish systems, and in sealing slurries. Its commercial name is VINNAPAS® RE 5044 N. The following Table 2 shows the properties of the PVA/VE used in the research (SpecialChem, 2013).

Table 2. Properties of PVA/VE (SpecialChem, 2014)

Typical Properties	Unit	Value
Solids content	%	98-100
Ash content @ 1000 ℃, 30 min	%	8-12
Apparent density	g/l	440-540
Particle size, over 400 microns	%	4
Particle size, predominant	microns	1-7
Minimum film-forming temperature	℃	0

2.2 Mix Proportioning

A trial mixes proportioning by weight was used for preparing the specimens. The mix designs were carried out for concrete grade 30. A total of 12 concrete mixtures were prepared by varying the proportions of binders within the calculated ranges. The water-to-binder (w/b) ratio was maintained at 0.48. Firstly, VA was used to replace

OPC at dosage levels of 5%, 10%, 15%, 20% and 25% by weight of the binder. Secondly, PVA/VE was used to replace OPC at dosage levels of 0.5%, 1%, 1.5%, 2% and 2.50% by weight of the binder. Finally, the optimum replacement levels of VA and PVA/VE were determined from the first and second stages respectively and used to prepare a new trial mix. The mix proportions were calculated for one cubic meter and presented in Table 3.

Table 3. Mix proportion for concrete grades 30 (for one cubic meter volume)

Mix	Cement (kg)	VA (kg)	PVE/VE (kg)	Water (ltr.)	w/b	Sand (kg)	Foliya (kg)	Adasia (kg)	Simsymia (kg)
Control	350.00	0	0	168.0	0.48	613.33	503.33	402.50	310.83
VA (5%)	332.50	17.50	0	168.0	0.48	613.33	503.33	402.50	310.83
VA (10%)	315.00	35.00	0	168.0	0.48	613.33	503.33	402.50	310.83
VA (15%)	297.50	52.50	0	168.0	0.48	613.33	503.33	402.50	310.83
VA (20%)	280.00	70.00	0	168.0	0.48	613.33	503.33	402.50	310.83
VA (25%)	262.50	87.50	0	168.0	0.48	613.33	503.33	402.50	310.83
PVE/VE (0.5%)	348.25	0	1.75	168.0	0.48	613.33	503.33	402.50	310.83
PVE/VE (1%)	346.5	0	3.50	168.0	0.48	613.33	503.33	402.50	310.83
PVE/VE (1.5%)	344.75	0	5.25	168.0	0.48	613.33	503.33	402.50	310.83
PVE/VE (2%)	343.00	0	7.00	168.0	0.48	613.33	503.33	402.50	310.83
PVE/VE (2.5%)	341.25	0	8.75	168.0	0.48	613.33	503.33	402.50	310.83
Proposed mix	292.25	52.50	5.25	168.0	0.48	613.33	503.33	402.50	310.83

3. Results and discussion

The results of all tests that have been performed on the trial mixes are shown below.

3.1 Workability of concrete mixes

The workability property of concrete mixes was measured by conducting slump cone test according to ASTM Standard C143-2003. Figure 3 shows the slump test results of concrete mixes.

The results in Figure 3 show that the slump of the concrete mixture containing VA decreases from 8.5 cm to 7.5 cm as the percentage of VA substitution increases from 5% to 25%. This result indicates that increased replacement level of VA increases the need for water in concrete mixture and can be attributed to the amount of replacement, the high specific surface area of the VA. The fineness of the particles, which is related to the specific surface area of VA, is the major factor that governs the reduction of workability when it is used in blended cement systems. Because the FA is finer than OPC, it resulted in an increased water intake; hence, the water requirement is higher. Moreover, Figure 3 shows that the slump of blended cement concrete containing PVE/VE is higher than that of the control concrete due to that PVE/VE is a water-redispersible that exhibits very good resistance to saponification. In addition, the results in Figure 3 show that the slump of the concrete mixture containing PVE/VE decreases from 16 cm to 14 cm as the percentage of PVE/VE substitution increases from 0.5% to 2.5%. The slump of C30 grade concrete for the proposed mixture, with 15% VA and 1.5% PVE/VE, exhibits an increase in slump of approximately 33.33% compared with the control mixture.

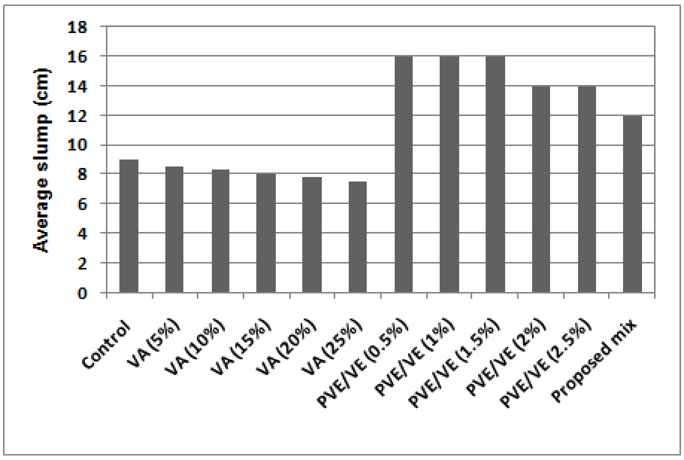

Figure 3. Average slumps of concrete mixes

3.2 Bulk density of cubes

The bulk density of hardened cement concrete was determined by measuring the dimensions and weights of the cubes before crushing at ages 7, 28 and 96 days. Figure 4 shows the average densities of cured cubes.

The bulk densities of blended cement concrete are lower than that of the control concrete. Figure 4 indicates that the densities of all the types of concretes, both with or without VA and PVE/VE replacement, increase with age. Figure 4 also shows the effects of VA and PVE/VE on the bulk density of blended cement concrete at 7, 28 and 96 days. As expected, the results show a decrease in density with an increase in VA and PVE/VE contents because the specific gravities of VA and PVE/VE are considerably lower than that of cement, which reduces the mass per unit volume. Furthermore, Figure 4 indicates that the proposed mixture, with 15% VA and 1.5% PVE/VE, exhibits a reduction in density of approximately 4.19%, 4.15 and 5.10% at 7, 28 and 96 days, respectively, compared with the control mixture.

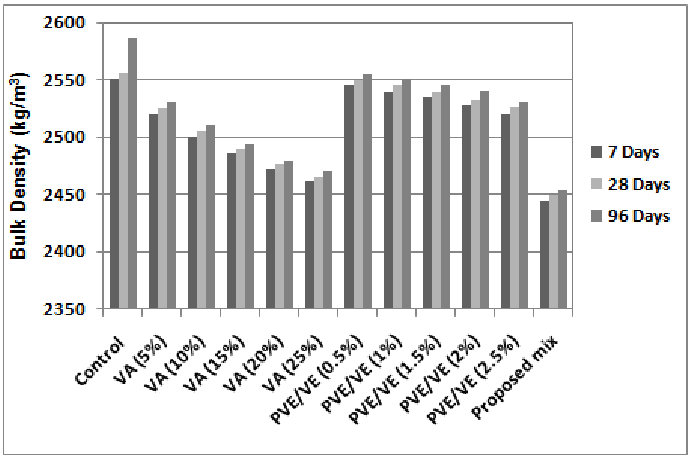

Figure 4. Bulk densities of concrete mixes

3.3 Compressive strength of concrete mixes

The test was conducted according to BS EN 12390-3 using a compressive machine with a load capacity of 5000 kN to obtain compressive strength of C30 grade of concrete. The compressive strength results of the C30 grade concrete at 7, 28 and 96 days age are presented in Figure 5.

Figure 5 indicates that there is a significant improvement in the strength of concrete because of the high pozzolonic nature of the volcanic ash and its void filling ability. The compressive strength of C30 grade concrete at 7, 28 and 96 days age with replacement of cement by VA was increased gradually up to an optimum replacement level of 15% and then decreased. The maximum 7, 28 and 96 days cube compressive strength of C30 grade concrete with 15% of VA was 401, 427 and 594 kg/cm^2 respectively. The compressive strength of C30 grade concrete with partial replacement of 15% cement by VA shows 17.94%, 25.64% and 32.65% for 7, 28 and 96 days respectively greater than the controlled concrete.

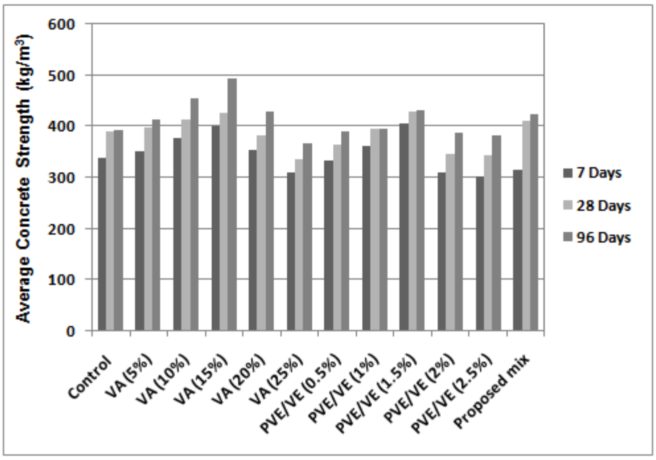

Figure 5. Average compressive strengths of concrete mixes

The compressive strength of C30 grade concrete at 7, 28 and 96 days age with replacement of cement by PVE/VE was increased gradually up to an optimum replacement level of 1.5% and then decreased. The maximum 7, 28 and 96 days cube compressive strength of C30 grade concrete with 1.5% of PVE/VE was 405, 430 and 432 kg/cm^2 respectively. The compressive strength of C30 grade concrete with partial replacement of 15% cement by PVE/VE shows 19.12%, 10.26% and 10.20% for 7, 28 and 96 days respectively greater than the controlled concrete.

Furthermore, Figure 5 indicates that the proposed mixture of C30 grade concrete, with 15% VA and 1.5% PVE/VE, exhibits an increase in compressive strength of approximately 7.35%, 5.13% and 7.91% at 7, 28 and 96 days, respectively, compared with the control mixture.

4. Conclusions

Great efforts are being taken worldwide to use of environmentally friendly supplementary cementing materials to reduce CO_2 emissions, save nonrenewable energy resources, provide aesthetically pleasing and healthy surroundings and at the same time minimize waste.

Based on the results presented above, the following conclusions can be drawn:

- Cement replacement up to 15% with VA leads to increase in compressive strength for C30 grade of concrete by 17.94%, 25.64% and 32.65% at 7, 28 and 96 days, respectively, compared with the control mixture.
- Cement replacement up to 1.5% with PVE/VE leads to increase in compressive strength for C30 grade of concrete by 19.12%, 10.26% and 10.20% at 7, 28 and 96 days respectively greater than the controlled concrete.
- Cement replacement up to 15% with volcanic ash and 1.5% with PVE/VE leads to increase in compressive strength for C30 grade of concrete by 7.35%, 5.13% and 7.91% at 7, 28 and 96 days, respectively, compared with the control mixture.
- The workability of cement replacement with VA was found to be decreased but the replacement with PVE/VE increased the workability of concrete.
- The bulk densities of all blended cement concrete are lower than that of the control concrete mixture at all ages because the specific gravities of VA and PVE/VE are considerably lower than that of cement, which reduces the mass per unit volume.
- VA can be used with PVE/VE as a partial replacement of cement for increasing the workability and strength of concrete.
- The use of VA and PVE/VE in concrete can solve the problem of its disposal thus keeping the environment free from pollution.

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