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Use of waste paper ash or wood ash as substitution to fly ash in production of geopolymer concrete

Key words: geopolymer concrete (GC), fly ash (FA), waste paper ash (WPA), wood ash (WA), alkaline solution

Introduction

Concrete is the most popular and widely used building material owing to availability of its raw materials and it combines good mechanical properties, durability, workability and it is relatively inexpensive. Ordinary Portland cement (OPC) is the key constituent binding material used in the concrete production, however manufacturing of OPC contributes substantially to global CO_2 emissions and energy consumption (Fairbairn et al., 2010). The main causes of high CO_2 emissions, which is known as the greenhouse gas rising from manufacturing of OPC have been attributed to the process of calcination of limestone and high energy consumption (Davidovits, 2011; Turner & Collins, 2013). Concrete is mainly used in the construction of buildings in civil engineering applications and infrastructure projects. Hence, the construction of buildings is under increasing pressure of developing green binder materials that possess the desired engineering properties to overcome the CO_2 emission and reduce the dependence on the OPC (Małaszkiewicz & Jastrzębski, 2018; Abdulkareem, Ramli & Matthews, 2019). Several alternative cementitious materials that are principally derived from industrial by-products can provide comparable performance to the OPC in a range of applications, but with an additional advantage of significantly reduced greenhouse emissions (Gartner, 2004). The alternative materials involve sugar cane bagasse ash (SCBA), fly ash (FA), metakaolin (MK), rice hush ash (RHA), blast furnace slag (BFS), vulcanic ash and bottom ash (BA) (Fernandez-Jimenez, Palomo & Lopez--Hombrados, 2006; Fairbairn et al., 2010; Risdanareni, Karjanto & Khakim, 2016;

Thaarrin & Ramasamy, 2016; Ekaputri & Junaedi, 2017; Mehta and Siddique, 2018), which contain much silica (SiO_2) and alumina (Al_2O_3). The most popular of these materials that considered in manufacturing GC is fly ash (FA), which is residue from the burnt coal, and it is available worldwide as a waste material (Ryu, Lee, Koh & Chung, 2013). An alternative concrete termed "geopolymer concrete" (GC) that based on one of the by-product materials as a substitute for OPC has been considered as environmentally friendly concrete (Hardjito, Wallah, Sumajouw & Rangan, 2004).

This concrete is formed by the alkaline activation of the aforementioned by-products materials to form an aluminosilicate gel structure through the polycondensation reaction. The alkaline activator used is commonly a combination of a hydroxyl, usually sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3) or potassium silicate (Turner & Collins, 2013). Besides, it is required to provide curing for GC with elevated temperature between 40°C and 80°C for at least 6 h to achieve an equivalent strength to OPC concrete (Duxson et al. 2007; Ryu et al. 2013). Beside the interest in finding low CO_2 emission and low energy consumption binders there is an interest in investigating the possibility of using the waste materials as the substitutes for OPC in producing of geopolymer concretes (Shi, Wu, Riefler & Wang, 2005). The construction industry offers reusability solutions for wastes due to the large consumption of materials and the large number of construction sites, thereby, in many developed economies, waste represents a resource that can be utilized for a diversity of beneficial purposes (Tam, Soomro & Evangelista, 2018). Huge amounts of paper and wood waste are generated every day due to the increase of production and population, the disposal of these waste to landfill is expensive in addition to the scarcity of suitable land that cause a number of pollution and environmental problems. Consequently, an economical alternative to landfill disposal is by reusing of waste materials, the waste reusability has many advantages, including the decrease in the waste volumes, the reduction of greenhouse gas emissions and the consumption of natural resources (Letelier, Henriquez-Jara, Manosalva & Moriconi, 2019).

Previous research has been published concerning the influence of using paper sludge ash on the properties of concrete and paste (Ishimoto, Origuchi & Yasuda, 2000; Bai et al., 2003; Frías, Garcia, Vigil & Ferreiro, 2008; García, de la Villa, Vegas, Frias & de Rojas, 2008; Mozaffari, Kinuthia, Bai & Wild, 2009). According to Pachamuthu and Thangaraju (2017), the improvement of the mechanical properties of GC that contains paper sludge ash depends on the percentages of paper sludge ash and the curing conditions. On the other hand, several studies (Etiegni & Campbell, 1991; Naik, Kraus & Siddique, 2003; Udoeyo, Inyang, Young & Oparadie, 2006; Chowdhury, Maniar & Suganya, 2015) were conducted to investigate the feasibility of the use of wood ash as a partial replacement material to OPC in making of blended mortar or concrete. This paper presents the feasibility of incorporating of waste paper ash (WPA) or wood ash (WA) as replacement materials for fly ash (FA)

(class F) in preparation geopolymer concrete (GC). The influence of the WPA or WA incorporation on the geopolymers' workability, compressive strength, splitting tensile strength and flexural strength has been studied and compared with neat FA geopolymer as a control mix.

Materials

Fly ash (FA), waste paper ash (WPA) and wood ash (WA)

In this study, fly ash FA (class F) that collected from Turkish hard coal from power station Iskenderun was used to produce GC mixes, the specific gravity of FA was 2.21 $g \cdot cm^{-3}$. It conforms to the ASTM standard specification C618--08a (ASTM International [ASTM], 2008). The waste paper ash (WPA) is a leftover material that has found in large quantities worldwide within offices, government departments and houses. The waste paper ash used for this study was collected from burning in oven up to 650 ±20°C, for 60 min, it has a specific gravity of 2.53 $g \cdot cm^{-3}$. Besides, wood ash (WA) obtained from industrial by-product such wood burning, it has a specific gravity of 2.31 $g \cdot cm^{-3}$. The chemical composition of FA, WPA and WA are listed in Table 1.

Fine and coarse aggregate

The fine aggregate used was natural river sand, free from loam and clay. The fine aggregate having specific gravity of 2.66 $g \cdot cm^{-3}$, with sulfate content of 0.23% and the grading of fine aggregate satisfies the requirements of Iraqi standard IQS 45/1984 (Iraqi Central Agency for Standardization and Quality Control [ICASQC], 1984) (Zone 2). While, the crushed gravel was used in this study with maximum size of 19 mm. The coarse aggregate having a specific gravity of 2.64 $g \cdot cm^{-3}$ and the sulfate ratio of 0.04% and it conforms to the IQS 45/1984 standard.

High-water range reducer

A high-water range reducer (SP400) has been utilized to enhance the workability of GC. It complies with the ASTM C494-C494M standard (ASTM, 2017).

Alkaline activator liquid

The alkaline liquid was obtained by blending solutions of sodium hydroxide and sodium silicate to activate the fly ash. Sodium hydroxide has flakey form and high purity more than 98%, which could be dissolved in the filtered water (molarity of solution of sodium hydro-

TABLE 1. Chemical composition of fly ash (FA), waste paper ash (WPA) and wood ash (WA)

Oxides [%]	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	L.OI
FA	65.65	17.69	5.98	0.98	0.72	1.35	2.99	0.19	3.1
WPA	47.80	27.00	2.34	6.53	3.32	3.50	6.38	1.10	1.13
WA	32.51	28.30	2.14	9.53	3.32	10.50	12.3	0.10	22.50

xide (10M). The sodium silicate Na_2SiO_3 as a solution is commercially available.

Experimental program

The experimental program consists of preparing and testing different GC mixes to examine the influence of incorporating WPA or WA on the properties of GC. The developed GC mixes for this study were prepared at replacement ratios of FA by WPA or WA of 25, 50, 75 and 100% in addition to a control mix containing 100% of FA. The tested mixes have been evaluated with respect to the workability, the compressive strength at ages of the tested specimens of 7, 28 and 56 days. Tensile splitting strength and flexural strength at age of the 28 days.

Mix proportions of GC mixes

Based on the geopolymer concrete mix designed by Rangan (2008), the GC mix was developed taken into account the workability and the ratio of silicate-sodium to sodium hydroxide solution was 2.5. The density of GC was 2,400 $kg \cdot cm^{-3}$. The mix proportions of all GC mixes are illustrated in Table 2.

Preparation of test specimens

The binder (FA, WPA or WA) was dry mixed with the fine and coarse aggregates using pan mixer for 4 min. Then, the superplasticizer dosages (SP) and the prepared alkaline activator liquid used of the GC mixes were mixed for 2 min and added gradually to the solid ingredients. Afterwards, the wet mixing continued for 5 min more until the mix was homogenized. For the workability evaluation, the fresh GC mixes were tested using slump test. The slump test was performed in accordance with the ASTM C143/C143M-05a standard (ASTM, 2005).

TABLE 2. Mix proportions of test GC mixes [$kg \cdot m^{-3}$]

Mix symbol	FA	Repl. [%]	WPA	WA	Fa*	Ca**	Alkaline liquid	Alkaloid to binder ratio	SP
GF-0	404	0	0	0	660	1 100	176	0.43	9
GF-P25	303	25	101	–	660	1 100	176	0.43	9
GF-P50	202	50	202	–	660	1 100	176	0.43	9
GF-P75	101	75	303	–	660	1 100	176	0.43	9
GF-P100	0	100	404	–	660	1 100	176	0.43	9
GF-W25	303	25	–	101	660	1 100	176	0.43	9
GF-W50	202	50	–	202	660	1 100	176	0.43	9
GF-W75	101	75	–	303	660	1 100	176	0.43	9
GF-W100	0	100	–	404	660	1 100	176	0.43	9

*fine aggregate, **coarse aggregate.

For evaluating the compressive, splitting tensile and flexural strengths, the fresh GC mixes were cast into cubic moulds of 100 mm, cylindrical moulds of 100 × 200 mm and prism moulds of 100 × 100 × 400 mm. After casting, the specimens were vibrated for 2 min on the vibration table to remove entrapped air. Thereafter, the moulded specimens were covered using a plastic sheet to prevent water evaporation. According to Rangan (2008), the effective curing temperature is 60°C, thus the specimens were then cured in an oven at a temperature of 60°C for one day.

Finally, the specimens have been left at room temperature until the testing date. The compressive strength test was conducted in accordance the BS 1881--116:1983 standard (British Standards Institute [BSI], 1983), while the splitting tensile strength was conducted according to the ASTM C496 standard (ASTM, 2004), and the flexural strength test was conducted according to the ASTM C78 standard (ASTM, 2002).

Results and discussion

Workability of GC mixes

The workability of all fresh GC mixes was measured immediately after mixing using slump test as for the conventional concrete. The SP was used to achieve the required slump with a dosage of 2.25% by weight of binder for all types of GC mixes and the liquid/binder ratio was kept of 0.43 for all the GC mixes. The slump values for all GC mixes were ranged from 98–104 mm as summarized in Table 3, the results showed there were no significant differences in the slump values for all GC mixes.

TABLE 3. The slump of GC mixes

Mix symbol	Slump [mm]
GF-0	104
GF-P25	98
GF-P50	101
GF-P75	100
GF-P100	102
GF-W25	99
GF-W50	103
GF-W75	101
GF-W100	99

Mechanical properties of GC mixes

The results of the compressive, splitting tensile and flexural strengths of GC specimens are in Table 4. The results of compressive strength of GC specimens were at ages of 7, 28 and 56 days and Figures 1 and 2 display the variations of compressive strength as the proportional percentages of compressive strength GC mixes to the control GC mixes (GF-0). As observed from Table 4 that the control mix GF-0 (100% FA) developed the highest compressive strength than the other blended mixes containing WPA or WA at the all ages, and the compressive strength of the control specimens increased after extended aging to 56 days. Results also show a small decrease in the compressive strength for GC mixes that incorporation WPA of 25% (GF-P25) at the all-tested ages and 50% (GF-P50) at 7 and 28 days in comparison with the GF-0. Whereas the GF-P50 at 56 days has more decrease in compressive strength as compared to the GF-0.

TABLE 4. Test results of the mechanical properties of GC mixes properties

Mix symbol	Compressive strength [MPa]			Splitting tensile strength [MPa]	Flexural strength [MPa]
	7 days	28 days	56 days	28 days	28 days
GF-0	42.38	57.73	61.51	3.52	4.85
GF-P25	42.00	56.78	59.86	3.41	4.77
GF-P50	41.82	55.53	56.88	3.21	5.02
GF-P75	39.18	52.43	52.26	3.10	4.35
GF-P100	35.12	49.28	50.37	2.93	4.10
GF-W25	41.10	55.24	57.82	2.92	4.55
GF-W50	34.11	49.27	53.58	2.54	4.35
GF-W75	29.22	43.13	47.75	2.30	3.83
GF-W100	20.00	39.5	44.21	2.10	3.17

On the other hand, excluding the GC mix incorporation WA of 25% (GF-W25) at ages of 7 and 28 days, the GC mixes inclusion WA of 50, 75 and 100% (GF-W50, GF-W75 and GF-W100) have the lowest compressive strength at all tested ages in comparison to GF-0 mix. Besides, it can be seen from Figures 1 and 2 that the most notable decreases in compressive strength appear in the mixes 100 % WPA (GF-P100) or 100% WA (GF-W100) compared to those of the control mixes (GF-0) at all tested ages. The compressive strength of the control mixes decreases by about 14, 17.6 and 18% and 52.8, 31.6 and 28% in the GC mixes incorporation 100% WPA or 100% WA at 7, 28 and 56 days

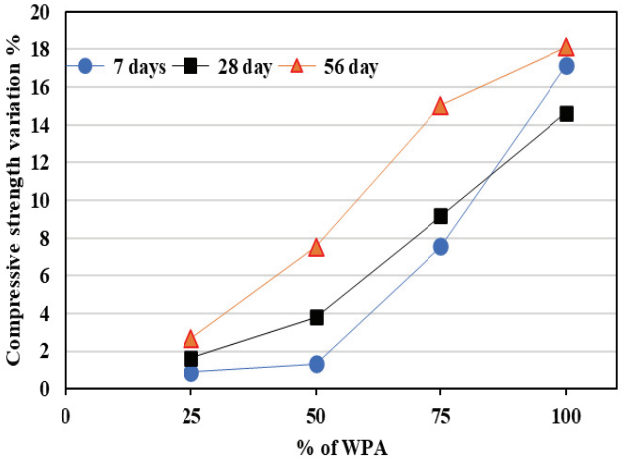

FIGURE 1. Compressive strength variation of GC mixes with replacement of FA by WPA

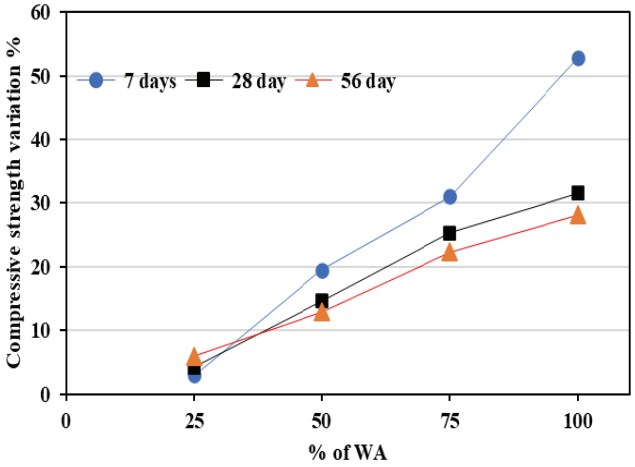

FIGURE 2. Compressive strength variation of GC mixes with replacement of FA by WA

respectively. Moreover, the reduction in compressive strength for GC mixes inclusion WA is more obvious than in mixes inclusion WPA. This may be due to the concentration of silicate through WPA more than WA, which affects the strength development due to higher silicates availability for the polymerization (Fernández-Jiménez, García-Lodeiro & Palomo, 2007). Also, the high CaO content present in WA causes reduction in strength of GC mixes (Astutiningsih and Liu, 2005; Luga & Peqini, 2019). Generally, the reduction of compressive strength for GC mixes as the replacement percentages of WPA or WA are increased, is justified due to the slower dissolution rate of WPA and WA in comparison with that high dissolution rates of the FA aluminosilicate, which has an impact on the strength development; as a result of reducing the silicon and aluminium ions (Shi et al., 2005).

The results of the splitting tensile strength of the GC specimens at age of 28 days are given in Table 4. Figure 3 displays the variations of splitting tensile strength as proportional percentages to the control mixes GF-0. As can be observed from these results that the splitting tensile strength of the control mix GF-0 (100% FA) developed the highest splitting tensile strength than the other blended mixes containing WPA or WA. The splitting tensile strength of the GC mixes inclusion WPA or WA reduced with increasing WPA and WA contents and the reductions were more pronounced when compared with reductions in compressive strength.

The splitting tensile strength of the control mix decreases by about 16.8 and 40.3% in the GC mixes incorporation 100% WPA or 100% WA respectively. Besides, the GC mixes inclusion WA showed lower values of the splitting tensile strength as compared to those obtained for GC mixes inclusion WPA.

The flexural strength results of the studied GC specimens at 28 days are presented in Table 4 and Figures 4 and 5. It is evident from the test results that the use of WPA or WA resulted in decrease in the flexural strength with

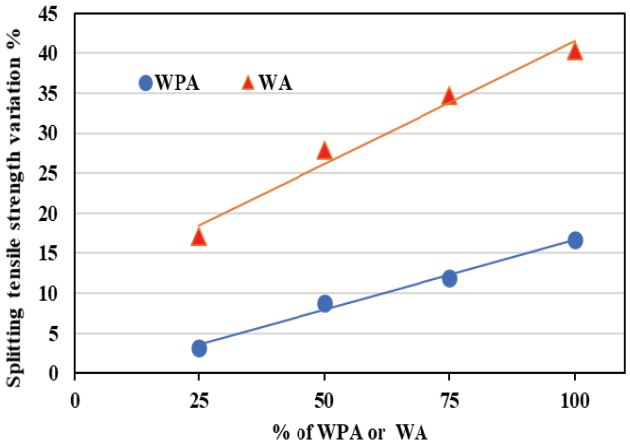

FIGURE 3. Splitting tensile strength variation of GC mixes with replacement of FA by WPA or WA

increasing WPA or WA contents excluding the GC mix with 50% WPA, which exhibited flexural strength greater than that of the control mix (GF-0). Further, the reductions in flexural strengths for GC mixes inclusions WPA or WA are close to those reductions in compressive strength for these mixes and less than the reductions in splitting tensile strength.

Figures 6 and 7 show the studied strength parameters (compressive strength, splitting tensile strength and flexural strength) at age of 28 days for GC mixes with replacement of FA by WPA or WA respectively. The decrease in the strength parameters occurred as the WPA or WA contents increase, which, can attributed to the silicate and aluminate contents and low value of pozzolanic reactivity of WPA and WA. Moreover, the reduction is more pronounce in GC mixes inclusion WA due to high content of CaO present in WA.

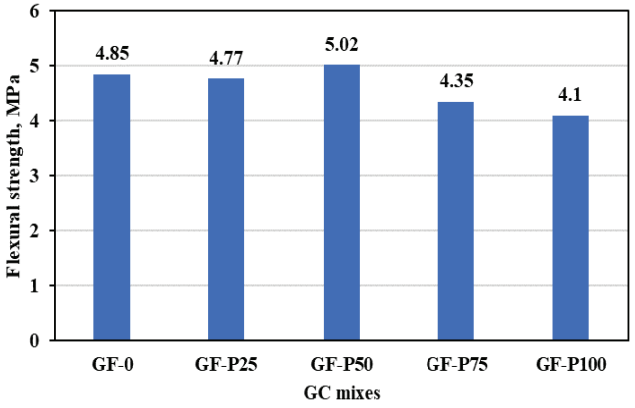

FIGURE 4. The flexural strength of the GC mixes with replacement of FA by WPA

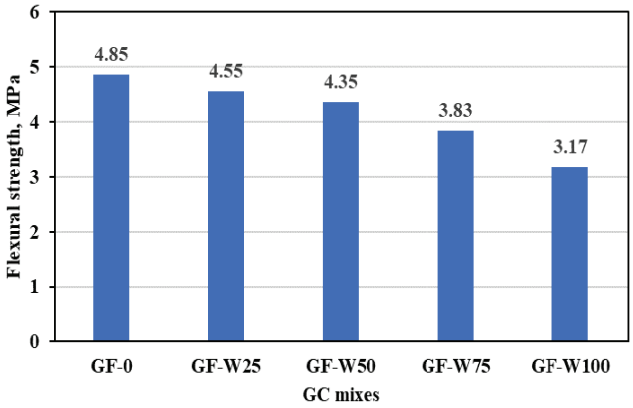

FIGURE 5. The flexural strength of the GC mixes with replacement of FA by WA

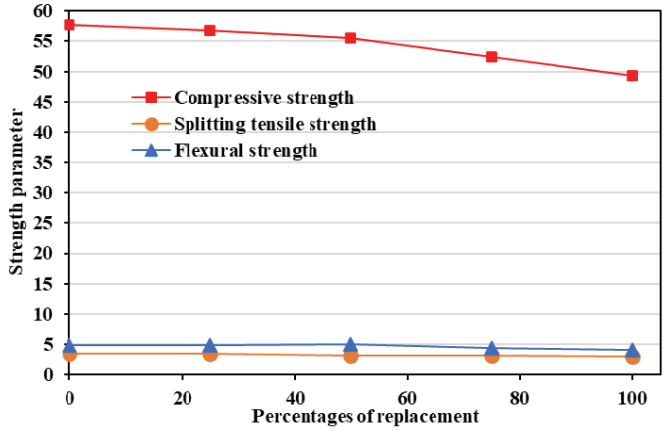

FIGURE 6. Strength parameters at 28 days for GC mixes with replacement of FA by WPA

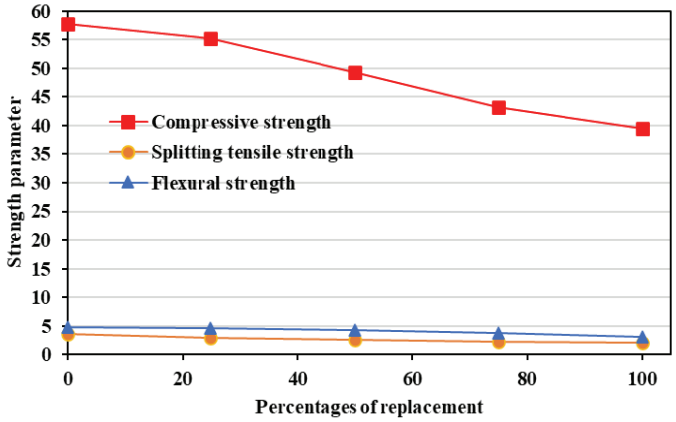

FIGURE 7. Strength parameters at 28 days for GC mixes with replacement of FA by WA

Conclusions

The properties of GC made with WPA from offices, and houses and WA from industrial waste replacing FA class F in absolute volume percentages up to 100% was evaluated in this study. The main conclusions are as follows:

– The results of the workability showed that there were no significant differences in the slump values of developed GC mixes with WPA or WA and the control GC mix (GF-0).
– The results of the development compressive strength of GC mixes inclusion 25–50% of WPA are close when compared with compressive strength of control mix of (GF-0). Replacement of 75–100% of WPA caused a further decrease in compressive strength of the GC mixes.
– The replacement with 25% WA had little effect on the compressive strength of GC mixes, while replacement with 50, 75 and 100% WA resulted in more reduction in the compressive strength of GC mixes in comparison with the control mix (GF-0).
– The splitting tensile strength of the GC mixes inclusion WPA is influenced with increasing WPA content, and the inclusion of WA as replacement for FA negatively affected the splitting tensile strength. The reductions in splitting tensile strength are more pronounced than the reductions in compressive and in flexural strengths.
– The reductions in flexural strength for GC mixes inclusion WPA or WA are close to those reductions in compressive strength for these mixes and less than the reductions in splitting tensile strength.
- From the present obtained results, it can be concluded that the GC mix with partial replacement of FA by WPA up to 50% or WA up to 25% can be satisfactorily used in preparation of the GC. Besides, utilizing these materials in developing GC has economic and environmental benefits.

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Summary

Use of waste paper ash or wood ash as substitution to fly ash in production of geopolymer concrete. Large quantities of paper and wood waste are generated every day, the disposal of these waste products is a problem because it requires huge space for their disposal. The possibility of using these wastes can mitigate the environmental problems related to them. This study presents an investigation on the feasibility of inclusion of waste paper ash (WPA) or wood ash (WA) as replacement materials for fly ash (FA) class F in preparation geopolymer concrete (GC). The developed geopolymer concretes for this study were prepared at replacement ratios of FA by WPA or WA of 25, 50, 75 and 100% in addition to a control mix containing 100% of FA. Sodium hydroxide (NaOH) solutions and sodium silicate (Na_2SiO_3) are used as alkaline activators with 1M and 10M of sodium hydroxide solution.The geopolymer concretes have been evaluated with respect to the workability, the compressive strength, splitting tensile strength and flexural strength. The results indicated that there were no significant differences in the workability of the control GC mix and the developed GC mixes incorporating WPA or WA. Also, the results showed that, by incorporating of 25–50% PWA or 25% WA, the mechanical properties (compressive strength, splitting tensile strength and flexural strength) of GC mixes slightly decreased. While replacement with 75–100% WPA or with 50–100% WA has reduced these mechanical properties of GC mixes. As a result, there is a feasibility of partial replacement of FA by up to 50% WPA or 25% WA in preparation of the geopolymer concrete.

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