New Environmentally Lightweight Building Materials from Hybrid Inorganic Polymer-Wood Particles

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Abstract

The use of environmental friendly building construction materials has become increasingly important. Geopolymer, an inorganic polymer material produced by the alkali-activation reaction, is well known as a potential replacement to ordinary Portland cement where it may allow significant reduction in carbon dioxide emissions. The utilization of wood particles has been developing rapidly in last decades. Due to its availability and low production cost, these natural resources have been used extensively in developing wood construction materials. In principle, most of the wood based construction materials are dominated by synthetic adhesives. Substitution material, especially formaldehyde-based adhesives to free formaldehyde, in wood products is vital to reduce pollutants from building materials and to control indoor air quality. This study aims at studying the properties of lightweight building materials, assemblies of wood particles and geopolymer. Processing parameters includingthe percentages of geopolymer materials and curing conditions, such as curing time and curing temperature are investigated. The mechanical and physical properties of each sample are measured. The findings from the research were encouraging and indicated that there is possibility of producing a new lightweight multifunctional construction material from hybrid inorganic polymer-wood particles.

*Keywords:*Wood particles, Lightweight, Building materials, Hybrid, Geopolymer

1.0 Introduction

Concrete industry is reported to be one of the main contributors of global warming due to the use of Portland cement as the main component in the production of concrete. However, the use of concrete is still unavoidable especially in construction materials. In order to address these concerns and other environmental problems relating to the use of cements, another form of cementitous materials, was discovered by Gluskhovsky in the former Soviet Union in the 1950s and developed by Davidovits in the late 1970s (Komnitsas and Zaharaki, 2007; Davidovits, 1994). Geopolymers have been successfully used in several industrial applications with excellent mechanical properties, high temperature resistance and at the same time improving the greenness of normal concrete (Duxson et al., 2007). Geopolymer materials contain aluminium (Al) and silicon (Si) species that are soluble in highly alkaline solutions. Any material that is rich in Si and Al in amorphous form can be a possible source material for geopolymer binder. Natural minerals or industrial wastes that have been used as raw materials are kaolinite, metakaolin, calcium- and silica-based geopolymer, fly ash, slag, silica fume, and natural pozzolans (Ahmaruzzaman, 2010).

Lightweight or foamed concrete consists of entrapped air voids (foams) created by suitable foaming agents in a cement paste or mortar. It possesses high flow ability, low self-weight, minimal consumption of aggregate, high specific strength and excellent thermal insulation properties (Abdullah et al., 2012). Some cement based building materials utilizing large amounts of cement in the final product is high in density (<1500 kg/m^3). These high density materials are difficult to handle, cut and transport. The manufacturing of foamed materials using geopolymer which includes useful characteristics for modern building techniques and constructions have attained a lot of interest (Kamarudin et al., 2011). The pore system in geopolymer based material is conventionally classified as gel pores, capillary pores, macro-pores due to deliberately entrained air, and macro-pores due to inadequate compaction. The density of foamed geopolymer normally ranges between 200-800kg/m^3 (Abdullah et al., 2012). Thermal conductivity, which one of the most important properties of building materials, functions as the densitydensity, meaning that good thermal insulating values require low density material.

Concrete exhibits brittle behavior due its low tensile strength. The addition of aggregates like cenosphere, expanded polystyrene, glass/carbon fiber and woody/non-woody materials is believed to assist overcoming the deficiency of the concrete (Alomayri et al., 2013). A previous study revealed that the tensile strength, a tensile strain, toughness and energy absorption capacity of concrete can be significantly improved by the addition of reinforcement material (Sarmin et al., 2014; Alomayri et al., 2013; Chen et al., 2014; Shaikh, 2013). Woody and lignocellulosic reinforcement in cementitous product is widely being researched because it considerably improves structural characteristics. In addition, these natural materials occupy a special attention due to the wide availability and low cost compared to synthetic materials. Until now the research towards using wood particles as an aggregate in geopolymer is still limited.

This paper emphasizes the potential to produce inorganic-bonded wood composites using geopolymer as an alternative to ordinary inorganic binders. The development on using wood particles aggregates in geopolymer lightweight composites is presented. The effect of varying the proportion of fly ash and metakaolin was measured using compressive strength specimens. The water absorption and oven dry density test was conducted to show that the specimens satisfied the lightweight material requirement.

2.0 Materials & Methods

Fly ash, metakaolin, sodium silicate (Na_2SiO_3), sodium hydroxide (NaOH), wood particles and hydrogen peroxide (foaming agent) were used to produce the lightweight geopolymer composite concrete. The fly ash used was Class F, provided by GK Kiel power plant, Germany, and its chemical composition are listed in Table 1. Metakaolin (brand name Argical M1000) is obtained from AGS Mineraux. The Na_2SiO_3 (brand name Betol 52 DS) composition was 30.2% SiO_2, 14.7% Na_2O and 55.1% H_2O with a SiO_2/Na_2O molar weight ratio of 2.0 with a density of 1.54g/cm^3 at 20^{o}C according to the specification of the producer (Woellner GmbH & Co. KG). Laboratory grade NaOH beads are from Fisher Scientific. The wood particles, obtained from a local particle board mill, were sieved to the average <1.5-3.0mm. The moisture content was 3.52%.

Table 1: Chemical composition (% mass) of fly ash used in this study (from GK Kiel power plant)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3	Carbon	Other	Total
56.8	23.8	6.79	2.9	1.28	0.43	1.99	0.67	0.43	3.5	1.41	100

In this study, six standard mix compositions; A, B, C, D, E and F are shown in Table 2. These standard mix compositions are determined from the pre-trial mix. The ratio of Na_2SiO_3/NaOH used in this research was fixed to 2.5. The aluminosilicate/alkaline activator ratio was increased to improve the workability. The solution is prepared by first dissolving NaOH in water and mixing with Na_2SiO_3. The solution is allowed to cool down at room temperature. The mix proportions ranging from 0% to 100% of fly ash and metakaolin, as well as the alkaline solution, the constant percentages of H_2O_2 and wood particles as shown in Table 2 were mixed for 10-15 minutes until homogeneity was achieved. The resulting sludge was poured into the 50 x 50 x 50mm³ molds. The samples were cured at two different conditions: (a) at 80^{o}C for 24 hours; (b) at room temperature (~22^{o}C) for 7 days.

Table 2: Mix composition used in this study

No	% Aluminosilicate		% Wood	% H_2O_2	Alum:AL	Na_2SiO_3:NaOH
A	100 fly ash	0 metakaolin	10	5	2.0:1.0	2.5:1.0
B	90 fly ash	10 metakaolin	10	5	2.0:1.0	2.5:1.0
C	80 fly ash	20 metakaolin	10	5	2.0:1.0	2.5:1.0
D	70 fly ash	30 metakaolin	10	5	2.0:1.33	2.5:1.0
E	60 fly ash	40 metakaolin	10	5	2.0:1.33	2.5:1.0
F	50 fly ash	50 metakaolin	10	5	2.0:1.33	2.5:1.0

The compressive test of the samples was performed on a MannheimerMaschinenfabrik Mohr &Federhaff AG testing machine using a speed rate of <10mm/min. The other tests include density and water absorption of the samples.

3.0 Results & Discussions

Table 3 present the compressive strength, oven-dry density and water absorption of the samples at two different curing conditions.

Table 3: Compressive strength, oven-dry density and water absorption of composition A, B, C, D, E, and F under

two different curing conditions

Sample Conditions	Compressive Strength (MPa)		Oven-dry Density (kg/m^3)		Water Absorption (%)	
	80°C	Room Temp.	80°C	Room Temp.	80°C	Room Temp.
A	15.06	14.87	1022	1030	18.69	19.5
B	14.79	13.14	1012	1038	21.30	21.67
C	14.22	13.79	1015	1036	21.52	22.09
D	14.38	13.57	1016	1005	21.96	24.41
E	15.02	13.97	1014	1039	21.34	26.31
F	14.44	13.89	1012	1013	22.86	26.15

3.1 Compressive Strength

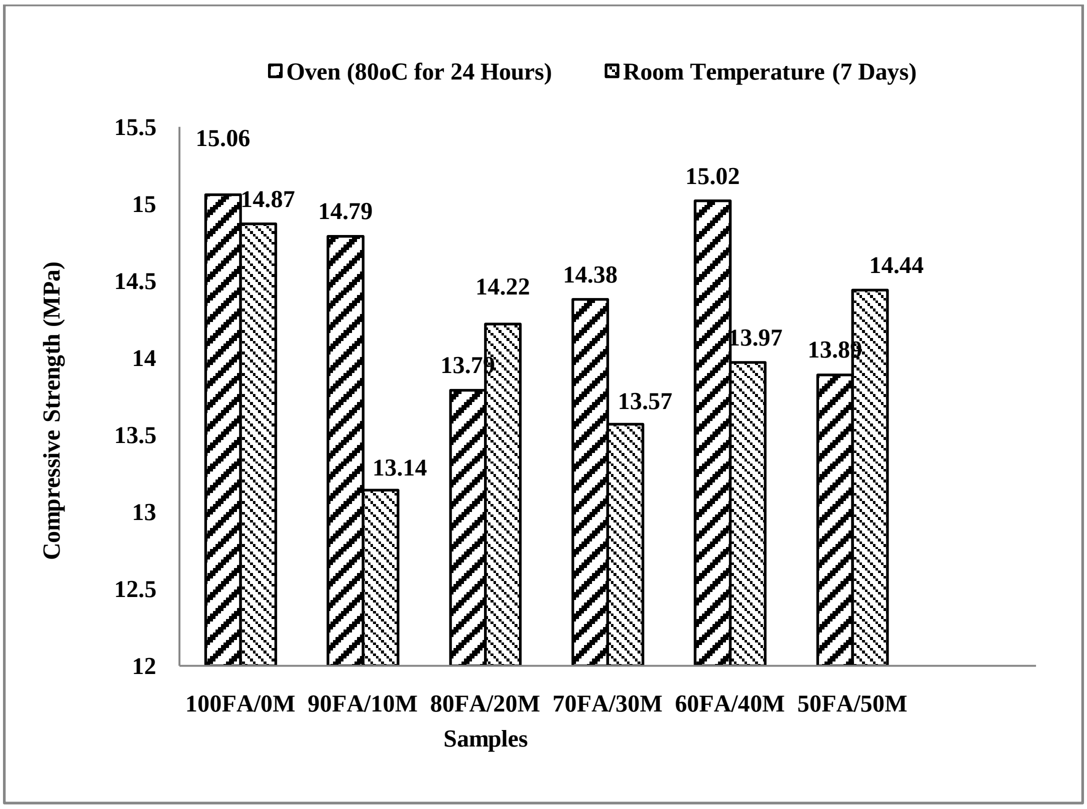

Figure 1: Compressive strengths for two different curing condition of lightweight geopolymer composite concrete with different proportion of fly ash and metakaolin

As shown in table 3 and Fig. 1, the maximum compressive strength was observed in the samples that had been cured in the oven. The maximum compressive strength values were 15.06 MPa for ‘A’ and 15.02 MPa for ‘E’ respectively. Thus, we concluded that the curing condition influenced the strength of the composites (Van Jaarsveld et al., 2002). For all six compositions, the strength of the sample cured at room temperature for seven days can be reached by accelerated curing at 80^{o}C in only 24 hours. This proved that heat treatment is required to expedite the rate of development of the strength of the geopolymer composite concrete.

Presently, there is no specification for inorganic polymer building units; therefore ASTM C90 is used as a reference for property evaluation. According to ASTM C90, lightweight specimens must show a minimum compressive strength of 13.1 MPa for the average of three samples and 11.7 MPa for each individual unit. The lightweight geopolymer composite concrete samples in this finding did meet the requirement for all different proportions of fly ash and metakaolin. The average strength of the samples cured at room temperature, however, are quite close to the minimum requirement for light weight mineral building materials. Such small strength deficiencies can be readily corrected by adjustment of processing parameters, e.g. by enlarging the curing time.

3.2 Oven Dry Density and Water Absorption

The result of oven dry density and water absorption are shown in Fig. 2 and Fig. 3. The average density of samples cured at 80^{o}C is 1015kg/m^3 and for room temperature sample is 1036kg/m^3 as stated in Table 3. The density of the lightweight materials depends on the porosity of the foamed geopolymer concrete where it is the sum of the entrained air voids and the voids within the paste (Wu and Sun, 2007). The higher compressive strength samples cured at 80^{o}C were achieved despite their lower oven–dry density and water absorption. In average, the samples cured in the oven at 80°C had lower oven-dry density and water absorption compared to the samples cured at room temperature.

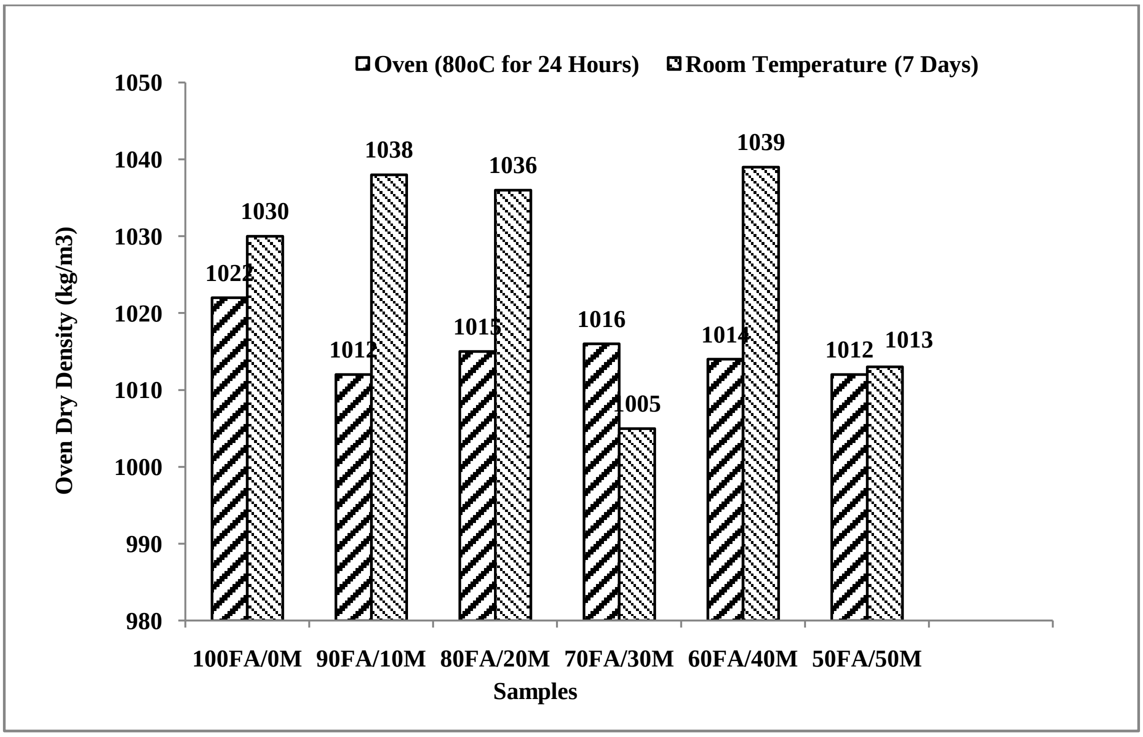

Figure 2: Oven-dry density for two different curing condition of lightweight geopolymer composite concrete with different proportion of fly ash and metakaolin

As can be seen in Fig. 3, the percentage of water absorption for all samples was slightly higher. The physical properties of wood itself, fibrous, hygroscopic and a lot of embedded network capillary in the fiber of wood particle are the main reasons behind the increasing magnitudes of water absorption(Simatupang and Geimer, 1990). The irregularity in shape and the highly porous surface contributed to the increment of water absorption percentage.

It is believed that wood contains covalent hydroxyl groups from residual lignin or both the cellulose component and the oxidation of end groups. As physical properties of wood particle have significant effects on adhesive criteria and the interface matrix with the geopolymer mixture, the characterization of the wood particle is mandatory to interpret the behavior of the wood particle being incorporated in the geopolymer matrix.

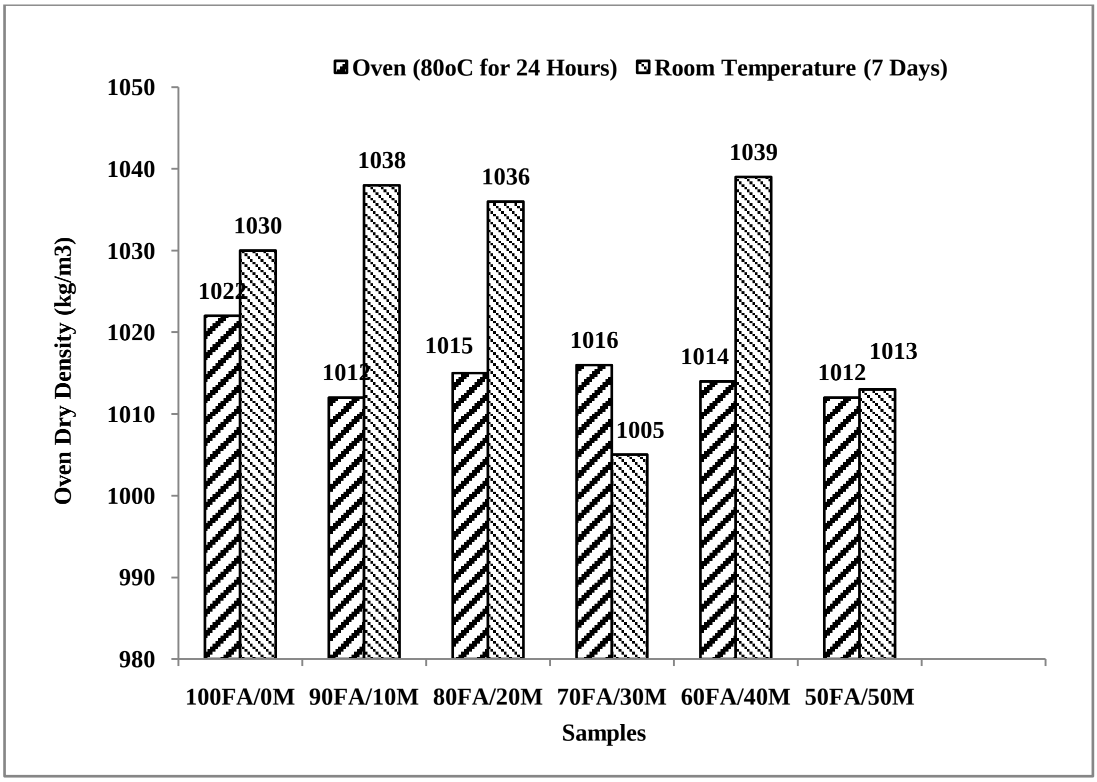

Figure 3: Water absorption for two different curing condition of lightweight geopolymer composite concrete with different proportion of fly ash and metakaolin

4.0 Conclusions

The average compressive strength of samples produced at two different curing conditions and various proportions of fly ash and metakaolin are meeting the requirement of the lightweight units. The strengths of the lightweight geopolymer composite concrete develop rapidly when it is cured at higher temperature than room temperature. The incorporation of wood fiber into the mixture may result in increasing magnitudes of water absorption in composite. An increasing amount of metakaolin and a reduction of the amount of fly ash may result in an increase of the oven-dry density and an increase of the strength of the lightweight geopolymer composite. The encouraging results of compressive strength and oven-dry density show the feasibility of producing wood particle reinforced geopolymer composite. Nevertheless, the results also indicate that there is a good potential of using geopolymer mortar as a substitute for organic binders in the manufacturing of wood based building materials.

5.0 References

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