A Study of Compressive, Flexural, Heat Humidity and Heat Transfer of Autoclaved Aerated Concrete Mixed Polypropylene Fiber under Climate of Bangkok

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Abstract: This paper presents the experimental results of study on mechanical properties, heat and humidity transfer through AAC (autoclaved aerated concrete) mixed with PP (polypropylene fiber). The performance of AAC-PP is investigated in terms of compressive strength, flexural strength, splitting tensile strength, porosity, heat and humidity capacity. The results are compared with control specimen made of autoclaved aerated concrete only (Non-AAC-PP). Results showed that ultimate compressive strength, flexural strength and splitting tensile strength can be obtained when the content of polypropylene fiber added at 0.75% by volume while porosity of specimens rapidly decreased when content of fiber addition increased above 1% of its volume. Additional, a comparison study of heat and humidity transfer properties on AAC-PP walls showed that the AAC-PP house had lower indoor air and moisture content than (Non-AAC-PP) house. Therefore, addition PP fiber on AAC increased mechanical properties, enhanced hygrothermal performance and reducing moisture content under tropical climate of Bangkok.

Key words: Autoclaved aerated concrete, Non-AAC-PP, polypropylene fiber.

Nomenclature

AAC-PP	Autoclaved aerated concrete walls mixed with polypropylene fiber
Non-AAC-PP	Non-autoclaved aerated concrete
Tamb	Ambient temperature (°C)
Two	Outside wall temperature of experimental house (°C)
Twi	Inside wall temperature of experimental house (°C)
Troom	Inside temperature of experimental house (°C)
Rh	Relative humidity (%)
W	Humidity (kg/kg)
db, dw	dry bulb globe thermometer and wet bulb globe thermometer
S, N, E, W	South, north, east, west of experimental house
1, 2	1st and 2nd experimental house

1. Introduction

Energy conservation issue has become a growing social public concern in Thailand since commodity prices have gone up. A problem of heat and humidity enters into house becomes house owner's concern

which increases electricity consumption of household and deterioration of household materials. An excessive heat and high humidity indoor can be occurred by several incidents. For example, high level of heat and moistures enters through building cavities, contact between indoor air and cold surface materials. Excess moisture often originates outside the structure as with foundation drainage problems, or it may be the result of activities by the occupants indoors. Cold surfaces usually are the result of air leakage or inadequate insulation in building cavities, or in rooms where less heat is provided. The high level of heat causes water vapor which creates moist and a different in temperature of two materials cause condensation [1]. Additional, the amount of excess heat and high humidity also increased when intensity of solar radiation hit on the outside wall increased and the duration of hit was longer [2]. The heat normally transfers from outside (high temperature region) to inside (lower temperature region) house by re-emitted process. The heat convection and heat radiation causes

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room temperature and temperature of objects inside the house increases. The transfer of heat appears in the form of sensible heat and latent heat of the objects. This is the result of difference in transferred vapor pressure from higher to lower area [3].

2. Literature Review

Thailand is a hot and rather humid tropical country with monsoonal climate. The hot climate caused roof to absorb heat and transfer to house which created an unbearable environment. However, the problem was usually solved by using air conditioner. This caused significantly increase in household electricity consumption by 60% [4]. Ogoli [5] studied methods of installing thermal insulation in the attic room. He found that plane insulation method was help to reduce in-house temperature. The average inside temperature was 22.4 °C and the outside was 25.4 °C. Cheng et al. [6] conducted the study on color painting affects wall temperature. He found that darker color had greater tendency in increasing room temperature than lighter color when wall materials were the same. In Thailand, Chantawong et al. [7] studied an affect of color painting on wall temperature. They found that heat capacity of exterior paint color with light gray colored, lily white color and light blue colored affected to house temperature. They further found that light paint color reflected sunlight whereas the darker color absorbed the sunlight. The result of their study showed that the light gray had the best performance as the thermal insulation. The thermal insulation ability was higher than lily white color and light blue color. The humidity and the relative humidity inside of the light gray painted house were lower than lily white and light blue color. Suksongyat et al. [8] conducted an experiment on heat and humidity transferred through the wall of experiment houses under Thailand climate. They found that different kind of materials gave different ability of heat and humidity transfer through masonry materials. There were four kinds of masonry materials studied (brickwork, autoclaved aerated concrete mixed with

microfiber, autoclaved aerated concrete mixed with sugar dregs and autoclaved aerated concrete only). The results showed that autoclaved aerated concrete mixed with sugar dregs wall gave the lowest room temperature. It was further found that the rate of heat transferred through the wall was also the lowest among other three masonry materials. Similar results were found from other researchers [9].

The aim of this research was to study heat transfer and humidity in house with AAC-PP and Non-AAC-PP walls under hot humid climate of Bangkok. The study was governed to considerable extent by the presence of wall without mortar on both inside and outside wall condition. This study was adopted from the study of Israngkura Na Ayudhya et al. [10]. They found that AAC-PP specimen gave higher mechanical performance of the restraint than Non-AAC-PP. Fiber addition helped increase AAC strength and also reduce the cost of cement ratio in mixture. The study was conducted in two experimental houses. Each house has similar volume of 4.05 m³. The normal temperature without air conditioner condition was applied. Therefore, the change in temperature, humidity, humidity inside house and walls temperature can be monitored.

3. Methodology

3.1 Detail of Design Mix

The cementitious materials used in this study were OPC (ordinary Portland cement) type I, which complied with BS 12:1991 [11] and ASTM C150-92 [12]. All AAC specimens were made by according to TIS (Thailand Industrial Standard) 1505-2541 [13]. The composition of AAC was shown in Table 1. The PP (property of polypropylene) fiber was shown in Table 2.

3.2 Preparation and Testing Methods

The materials were mixed according to ASTM C192 [14]. Coarser materials were first added to the mixer,

Table 1 Composition of AAC.

Composition (%)	Limestone	Cement	Sand	Perlite
SiO ₂	-	21.02	85	71.02
Al ₂ O ₃	0.5	5.21	6.1	16.09
Fe ₂ O ₃	0.5	3.17	1.2	7.01
CaO	80	65.46	0.36	0.58
MgO	1	3.14	0.85	0.41
Na ₂ O	0.2	0.14	1	0.90
K ₂ O	0.42	0.83	1	5.59

Table 2 Properties of polypropylene fiber.

Properties	Data
Specific gravity	0.91
Tensile strength (MPa)	300-400
Modulus of elasticity (MPa)	8,000
Elongation at yield (%)	13
Water absorption	0
Range of melting temperature (°C)	160-175
Evaporation point (°C)	341
Burning temperature (°C)	460

followed by approximately one-third of mixing water. Finer cementitious materials and water were added to the running mixer in a gradual manner. Fiber was then added gradually to running mixer. The addition of PP fiber usually takes about 2 min. Then, the mixer continued without fibers continues for 3 min. After 3 min, the final mixing takes 2 min. In this studied, there were two different types of specimens used. The compressive and splitting tensile strength test, the specimens were casted in cylindrical molds, 102 mm in diameter and 204 mm in height. In two layers, each layer being consolidated using a vibrating table. The heat transfer and humidity test, the specimens were cast in standard commercial molds with dimensional of 300 mm × 600 mm × 75 mm. In porosity test, the specimens were cut into cube shape with dimensions of 50 mm × 50 mm × 50 mm. All AAC specimens were then kept in pressurize chamber at the pressure of 10-12 bars, temperature of 180-190 °C for 8 h. The specimens were cut into standard sizes and required test amount by electric cutting device. The size accuracy was measured by vernier caliper instrument. The specimens were then placed in the oven at the temperature of 75 °C for 24 h.

Compressive strength tests were carried out in accordance with ASTM C39 [15] and splitting tensile strength tests were done according to ASTM C496 [16]. Flexural strength test were complied with ASTM C78/78M [17]. And, porosity test were conducted by vacuum saturation apparatus. Each data point reflects the four test results. The heat transfer and humidity of AAC house was tested according to Israngkura Na Ayudhya et al. [18]. Two experimental houses were built on open top floor of 63th building in College of Industrial Technology King Mongkut's University of Technology North Bangkok. The first experiment house was built with AAC-PP block whereas the second experimental house was built with AAC mixed without PP block (Non-AAC-PP). The dimensions of panel wall were 1,500 mm × 1,800 mm × 75 mm. The total surface area of each side-wall was 2.7 m². The surface of interior and exterior wall was refrained from mortar. The roof panel was clay tile beveled with 30° lined with heat reflection aluminum foil. The roof panel was made by CPAC (Concrete Product and Aggregate Co., Ltd). The gypsum board was used as cover ceiling with the thickness of 1 mm. The gypsum board acted as thermal barrier which can protect heat transfer through the attic to the experimental room. The plastic door (1,500 mm × 75 mm × 35 mm) was mounted on east side wall in each experimental house. Window glass (500 mm × 800 mm × 6 mm) was fitted at west side wall. The heat and humidity measurement instruments were located inside house (Figs. 1 and 2).

4. Results and Discussion

4.1 Compressive Strength

The compressive strength results of AAC-PP and Non-AAC-PP were shown in Table 3. The compressive strength increased with an increase in PP fiber content especially at 0.75% by volume where compressive strength of more than 2.88 N/mm² was found. The strength increased by 46.9% when compared with Non-AAC-PP specimen. However, PP fiber content increased from 0.75% to 1.0%, 1.5% and

Fig. 1 Houses in experiment.

Fig. 2 Dimensions of the test houses and positions of temperatures measurement.

Table 3 Compressive and splitting strength test results.

Mix (% fiber)	Porosity (%)	AAC		
		Compressive strength (N/mm ²)	Flexural strength (N/mm ²)	Splitting strength (N/mm ²)
0	99	1.96	1.26	0.82
0.5	98	2.04	1.28	0.81
0.75	97	2.88	1.37	0.87
1.0	95	2.51	1.25	0.81
1.5	94	2.04	1.23	0.79
2	93	1.92	1.20	0.78

2%, compressive strength decreased 14.7%, 41.2% and 50%, respectively. This was due to amount and

orientation of disperse of fiber which obstructed the voids. The interfacial bond between microfiber and

disconnected air voids in AAC were weak. Furthermore, polypropylene fiber was chemically inert and hydrophobic, thus the potential for chemical bonding was limited [19]. Therefore, it appeared that an optimum compressive strength occurred at 0.75% microfiber dosage.

4.2 Flexural Strength

The flexural strength results of AAC-PP and Non-AAC-PP specimens were shown in Table 3. The result of experiment clearly showed that an increase in the amount of fiber content up to 0.75% by volume had increased the flexural strength. Similar to the results of compressive strength, an increasing flexural strength of specimens was found to relate to the decrease in porosity of concrete. The flexural strength of all specimens was in the range of 1.20-1.26 N/mm². However, the flexural strength decreased significantly when the amount of PP content increased above 0.75% by volume. Similar results were found by Qian [20]. Therefore, the flexural strength was at the highest of its strength when fiber content was at 0.75% by volume. It gained 8.7% strength compared to Non-AAC-PP specimens.

4.3 Splitting Tensile Strength

It was found from Table 3 that an average splitting strengths of AAC and AAC mixed with PP fiber at 0.5%, 0.75%, 1.0%, 1.5% and 2% were 0.82 N/mm²,

0.81 N/mm², 0.87 N/mm², 0.81 N/mm², 0.79 N/mm² and 0.78 N/mm², respectively. The splitting tensile strength increased when the content of PP increased. However, the PP content did not show result in a significant improvement in the splitting tensile strength for the specimens. Similar results have been reported by other researchers [21].

4.4 The Correlations between Porosity and Content of PP and Porosity and Strength

It has been found from Fig. 3 that the porosity of specimens decreased when the content of PP addition increased. The porosity of specimens rapidly decreased when the content of PP was above 1% by volume. Regard to the correlation between porosity and strength, the result showed in Fig. 4 that the compressive strength of specimens increased when the porosity of specimens increased up to 97% by volume. However, the compressive strength rapidly decreased when the porosity of specimens was higher than 97% by volume. It was further found that the compressive strength had significantly affects on the amount of PP addition more than flexural strength and splitting tensile strength. Therefore, it appeared that the optimum point of content of PP mixed was at 0.75% by volume for obtaining the ultimate strength. The flexural strength was at 1.37 N/mm² and the splitting tensile strength was at 0.87 N/mm².

Fig. 3 The comparative between content of PP and porosity.

Fig. 4 The comparative between porosity and strengths.

4.5 Heat Transfer and Humidity

Based on strength and porosity test results in Table 3 and Fig. 4, respectively, it was found that the LWC (light weight concrete) decrease in thermal conductivity is due to the decreasing of concrete density. Similar results were found by Demirboga [22, 23] and Demirboga et al. and Blanco et al. [24, 25]. The thermal conductivity increases with the increase in the density of LWC. Therefore, the heat transfer and humidity test were then conducted on AAC-PP house mixed with 0.75% fiber addition. AAC-PP (0.75% fiber addition) specimen gave the highest strengths with porosity of 97% by volume. The heat transfer and humidity results of AAC-PP and Non-AAC-PP house can be seen in Fig. 5. The graphical data showed the change in temperature of the environment (T_{amb}) and intensity of solar radiation from two experimental houses. During studied, the temperatures of surrounding experimental houses were in the range of 27-37 °C (6:00 a.m.-3:00 p.m.). Intensity of solar radiations varied from 12-671 W/m² (7:10 a.m.-12:10 p.m.). The speed of wind was in the range of 0.32-1.87 m/s.

The comparison results of room temperature (T_{room}), humidity (R_h , %), environment temperature (T_{amb}) and air moisture (W) of two experimental houses were showed in Fig. 5. It was found that temperature inside AAC-PP house was lower than

Non-AAC-PP house about 0.5-3 °C. It was further found that the temperature inside both experimental houses was also lower than environment temperature (T_{amb}). However, the indoor temperature of west wall surface of AAC-PP and Non-AAC-PP house was higher than the environment temperature (Fig. 6). This was due to the characteristic of thermal insulation of PP fiber which reduced accumulated heat on the layer of material and enhanced heat transfer of AAC-PP wall [26]. Therefore, it helps conservation energy from using air conditioner.

Figs. 7 and 8 showed the change in temperature of outside wall surface (T_{wo}), temperature of inside wall surface (T_{wi}), north wall surface temperature ($T_{w, N}$) and west wall surface temperature ($T_{w, W}$) of two experimental houses. It was found that west wall of two experimental houses received solar radiation directly during the sun light. The temperature of outside west wall surface of two experimental houses was moderately the same. Whereas, the temperature outside west wall surface was higher than the environment temperature. This caused temperature outside north wall surface of two experimental houses was higher than the environment temperature. This was a result of reposition of the sun to the west. The north wall of both experimental houses received incidence solar radiation on the wall surface. However, it was found that the temperature inside both experimental

Fig. 5 Hourly variations of ambient temperature, solar radiation and indoor temperature of AAC-PP and Non-AAC-PP houses (December 15-16, 2010).

Fig. 6 Hourly variation of the ambient and west wall temperature of AAC-PP and Non-AAC-PP houses (December 15-16, 2010).

Fig. 7 Hourly variation of the ambient and north wall temperature of AAC-PP and Non-AAC-PP houses (December 15-16, 2010).

Fig. 8 Hourly variation of ambient and south walls temperature of AAC-PP and Non-AAC-PP houses (December 15-16, 2010).

Fig. 9 Hourly variation of ambient and east walls temperature of AAC-PP and Non-AAC-PP houses (December 15-16, 2010).

Fig. 10 Hourly variation of comparison for humidity and moisture content indoor of houses with AAC-PP and Non-AAC-PP (December 15-16, 2010).

houses was almost equal to the environment temperature. The average of solar radiation illuminance was measured at 671 W/m^2 . Regards to the temperature changed on the west wall surface (T_w, W) (Fig. 6) and the east wall surface (T_w, E) of AAC-PP and Non-AAC-PP experimental house (Fig. 9), it was found that the temperature inside and outside of west and east wall surface of Non-AAC-PP house was higher than west and east wall surface of AAC-PP house. Furthermore, the inside and outside temperature of west and east wall surface of AAC-PP house was also higher than environment temperature during 6:00 a.m.-15:00 p.m.. Fig. 10 showed the results of study on humidity, moisture inside both experimental houses. An accumulated vapor in the air and other objects in the houses volatilized when obtained heat from outside and the environment increased. It was found that humidity and moisture of environment was higher than humidity and moisture air inside of both AAC-PP and Non-AAC-PP experimental houses. This was due to the rain. It increased the humidity of surrounding environment. This caused the humidity and moisture inside AAC-PP and Non-AAC-PP experimental house is high. However, the humidity and moisture inside of both experimental houses were almost similar. Regard to the change of the heat through the west wall surface of experimental houses, it was found that the amount of detected heat reduced by 38.46% in AAC-PP house when compared with Non-AAC-PP house.

5. Conclusions

Based on the experimental study conducted and the discussion, it can be concluded that the PP increased the compressive strength, flexural strength and splitting tensile strength. It was found that the ultimate strength was at 0.75% by volume of fiber dosage. However, fiber addition has an effect on compressive than flexural and splitting tensile strength. The fiber addition increased the strength of compressive, flexural and splitting tensile by 47%, 9% and 6%, respectively. The behavior of AAC-PP specimens confirm generally

accepted that with an increasing porosity the strength of the AAC-PP decreases. The strength of AAC-PP decreased with an increased fiber dosage. The performance of thermal insulation AAC-PP house was higher than Non-AAC-PP house. The humidity in AAC-PP house was lesser than Non-AAC-PP house. It reduced heat by 38.46% when compared with Non-AAC-PP house. It appeared that PP fiber could save energy. Therefore, composites materials have the potential to be applied for green construction materials areas and also may be an alternative material to the industrialization of the construction materials. However, great care of mixing fiber should be taken. The PP fiber in aqueous suspensions is subjected to flocculation effects that involve scales of dosage. Increases in flocculation also tend to reduce the strength of AAC. The fiber disorientation occurred when AAC-PP specimens were placed near high steam temperature nozzle in autoclaved chamber. This could also affect the strength of specimens.

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