LIGHT WEIGHT SANDWICH PANELS BASED ON AIR-CURED PVA FIBER CEMENT SHEETS AND EXPANDED CLAY GRAVEL CONCRETE

DO QUOC QUANG[1], DAO DUC PHONG2, NGUYEN VAN HUONG[2], DINH CONG HUNG[3], NGUYEN DINH KIEN[1]

1 Viet Trust Engineering Consulting Co. Ltd., Hanoi, Vietnam, e-mail:quangdq50@gmail.com

2 An Quy Hung Co. Ltd., Hanoi, Vietnam,

3 The University of Fire Fighting and Prevention, Hanoi, Vietnam,

ABSTRACT.

The development of lightweight sandwich panels using PVA fiber cement sheets as skin layers and expanded clay gravel (Keramzit) concrete as a light weight softcore in Vietnam is described. Various tests for determining the physical and mechanical properties of the panels are presented. The potential of the panels for housing development and partitions of high buildings is discussed.

KEYWORDS:

Lightweight sandwich panel, air-cure PVA fiber cement sheets, expanded clay gravel concrete, Keramzit, physical and mechanical property.

INTRODUCTION

The traditional building materials are now facing many problems, including the strict regulations of using natural sources, high cost of manpower and time consuming of construction execution. The buildings using the traditional materials also have a disadvantage from energy saving point of view due to the high thermal conductivity of the partition walls and roofing.

Some new materials have been developed in recent years for overcoming the above disadvantage of the traditional building materials. Lightweight sandwich panels, which have high potential in application in Vietnam and other countries, are such materials [1]. These panels are usually fabricated in the factories, and thus their quality can be controlled properly. The panels with a large size (usually 610mm width, 2440mm length and a thickness between 60 and 90mm) are assembled by using prefabricated joints help to considerably reduce the construction time and subsidiary materials. Though the panel thickness is smaller than that of the traditional brick walls, but thanks to the sandwich structure, the mechanical strength of the panels is relatively higher, and because of thermal insulation of the softcore material, the energy saving of the building constructed from these panels can be greatly improved.

Sandwich panels in Vietnam

AQH (An Quy Hung Ltd. Co.) is the first company in Vietnam to install a lightweight sandwich panel line. The panels of AQH formed from two skin layers and a light weight softcore, in which the layers are air-cure PVA fiber cement sheets and the softcore is light weight EPS (expanded polystyrene) concrete. The AQH's panels with good adhesion between the skin layers and the core have been used in various buildings in Vietnam, for both indoor and outdoor applications.

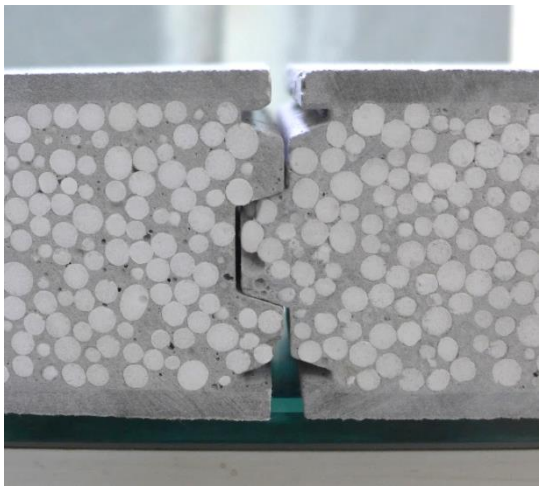


Figure 1: Prefabricated joints for assembly and a sandwich panel wall.

Some applications of sandwich panels are shown in figures 1-3. The walls used sandwich panels are light weight and easy to construct. With the Keramzit softcore, buildings using the sandwich panels are good in thermal and sound insulation and environment friendly also. Moreover, the panels can be used as the partition walls for high rise building.

Figure 2: Building walls using sandwich panels

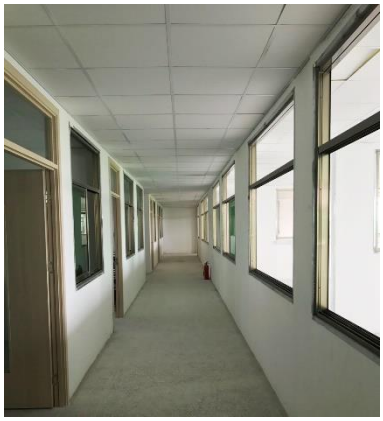


Figure 3*:* Partition walls using sandwich panels

Some main features of the AQH's EPS sandwich panels are as follows:

- *Advantages:*
  - Lightweight, easy to install, manpower saving, and using fewer subsidiary materials compares to the traditional bricks.
  - Good physical and mechanical properties, and suitable for partition wall, ceiling and floor structures of civil building and offices, etc.
  - Good thermal and sound insulation, especially good for roofing in the tropical regions where the temperature is high.
  - Good fire-resistant property, and fire-resistant time meets the requirements of Vietnamese standards.
- *Disadvantages:*
  - Polystyrene is used as lightweight material in the softcore, and this material generates toxic smoke during fire.
  - The possibility of recycling is very low and resulting in environmental problems due to the fact that polystyrene is hardly decomposed in natural environmental conditions.
  - For countries with petrochemistry which has not been developed like Vietnam, polystyrene must be imported.

Furthermore, due to the construction regulations, namely some buildings require fire-proof partition walls, and this requires sandwich panels with high fire-proof property and without toxic smoke in fire. In addition, the use of local materials which enable recycling, this is also a factor in consideration of making panels.

After consideration of some local materials, from both supply availability and cost points of view, we decided to use expanded clay gravel Keramzit as the lightweight material for the softcore.

SANDWICH PANELS USING KERAMZIT

Keramzit for softcore

Due to the above-mentioned disadvantages of the EPS sandwich panels, Keramzit have been employed as a replacement for EPS. Keramzit gravels, as depicted in Figure 4, are a lightweight material for the use as a filler of mortars or concretes. The gravels are fabricated by mixing a mixture of clay and some cheap organic admixtures such as coal powder, sawdust and pelletilized. The gravels are then burnt in high temperature (up to 1200oC) and expanded in to porous particles. The Keramzit have relative stable structure with porosity volume fraction up to 70%, in which 98% are micro porosities with size of micrometer. After burning, Keramzit particles are classified into particles with different size. The commercial Keramzit have a density of about 400 - 700kG/m3, and a conductivity λ = 0,05 – 0,2W/m.oC. Table 1 lists the main properties of the Keramzit for fabrication of the softcore of sandwich panels.

Figure 4: Commercial Keramzit gravels [2].

Several organizations in Vietnam have used Keramzit to fabricate lightweight concrete. However, the application of this concrete is still limited due to the concrete is easily broken during the construction. Figure 5 shows a sample of the Keramzit lightweight concrete.

Table 1: Properties of Keramzit used for softcore of sandwich panels [2]

Commercial name	Particle size (mm)	Bulk density (kg/m3)	Compressive in cylinder (MPa)	Water absorption	Thermal expansion coefficient (W/m.k)
S400	10-20	400-500	1.4	30%	0.09
S500	4-8	500-600	1.9	25%	0.1
S600	0-4	600-700	3.3	20%	0.12

Figure 5: **Light weight concrete for using Keramzit [3]**

The mix proportions of the light weight concrete for the softcore of sandwich panel using Keramzit are given in Table 2, where for the comparison purpose, the mix proportions using EPS are also given.

Table 2: Mix proportions for light weight softcore concrete using Keramzit and EPS

No.	Sandwich panel with Keramzit softcore		Sandwich panel with EPS softcore	
	Material	Rate (% volume)	Material	Rate (% volume)
1	Keramzit	47.62	EPS	50.42
2	Fly ash	10.8	Fly ash	10.8
3	Cement	14.6	Cement	14.6
4	Additives	0.03	Additives	0.03
5	Water	26.8	Water	24
6	Air bubble	0.15	Air bubble	0.15
	Total	**100**	**Total**	**100**

Skin layers

Skin layers of the lightweight panels used here are the air-cured PVA fiber cement flat sheets. The sheets with thickness of 5mm are fabricated by using Hatschek process, as seen from Table 3 [4], show good mechanical strength and impact resistance. The fracture energy of the PVA cement sheets, as shown in [4], is much higher than that of autoclave, and thus using PVA fiber cement sheets instead of the autoclave sheets as the skin layers can considerably improve the impact resistance of the sandwich panels.

The main materials for fiber cement skin layers are Portland cement, fly ash, pulp, silica fume, bentonite and PVA fibers (Kuralon A8 of Kuraray, Japan). After forming from Hatschek process, PVA cement sheets are pressed with a pressure of 50kG/cm2 and then cured in a steam chamber for 8 hours. The sheets are then covered by PVC membranes and kept in natural conditions of warehouse for 15 days before using. Table 3 lists some mechanical properties of the PVA cement sheets for the skin layers of the sandwich panels.

Table 3: Properties of PVA fiber cement sheets tested according to ASTM 1186-08

No.	Properties	Unit	Value
1	Specimen size	mm	305x127x5
2	3-point flexural test (ASTM C1186-08, span: 254mm)		
	In the machine direction (MD)	MPa	20.6
	In the cross direction (CD)	MPa	13.4
3	Water absorption	%	19.78
4	Natural humidity	%	8.9
5	Drying shrinkage	%	0.114
6	Fracture energy	J	2.62

Properties of light weight sandwich panels

In order to determine the mechanical properties of the light weight sandwich panels, several tests have been carried out, and the results are reported in this section. For the comparison purpose, both the specimens of the Keramzit softcore and EPS softcore panels have been used in the test.

Test specimens

In order to avoid possible defects during the manufacture process, the test specimens have been prepared manually by using metal molds. Three following types of specimens have been prepared:

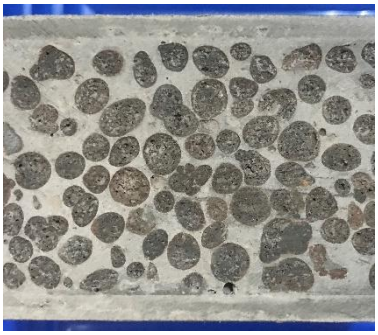
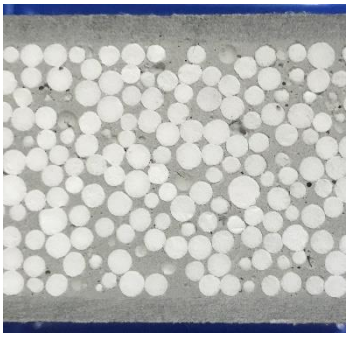
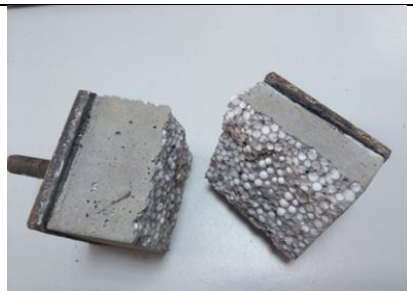
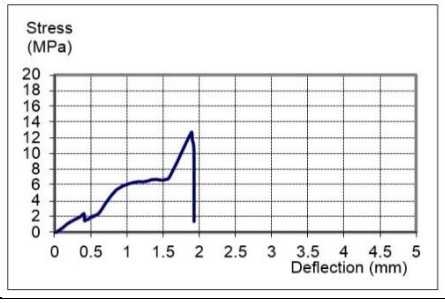
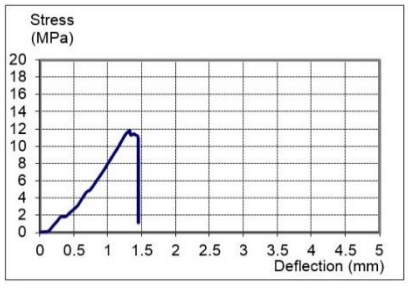
- Cubic specimens for compressive and layer de-bonding tests: 70x70x70mm
- 4-point flexural test specimens: 60x80x600mm (thickness x width x length)
- Fire resistant specimens: 60x480x480mm (thickness x width x length)

The specimens are kept dry in room condition (25^{o}C) for 21 days before testing.

MECHANICAL PROPERTIES:

The main mechanical properties, including the density, water absorption, compressive and flexural strengths of the panels are given in Table 4. As seen from the table, the density of the Keramzit panels is considerably larger than that of the EPS panels. The strength of the two panels is also different, namely the compressive and adhesion strengths of Keramzit panels are significantly higher than that of the EPS panels, while its flexural strength is slightly higher than that of the EPS panels. In general, the mechanical properties of the Keramzit panels are superior compare to that of EPS panels.

Table 4: Properties of Keramzit and EPS softcore panels

	Property	Keramzit soft-core	EPS soft-core
			
1	Density (g/cm^3)	1.253	0.960
2	Water content (%)	7.96	8.57
3	Water absorption (%)	15.4	18.87
4	Compressive strength (TCVN 3118-93, N/mm^2)	8.56	0.31
5	Adhesion strength (ASTM C393, N/mm^2)	0.70	0.31
6	Failure mode		
7	Drying Shringkage JIS A 5430:2004	0.081	0.093
8	Bending strength (Mpa, ASTM D7249)	12.71	11.84
9	Bending stress-deflection curves		

Fire resistance:

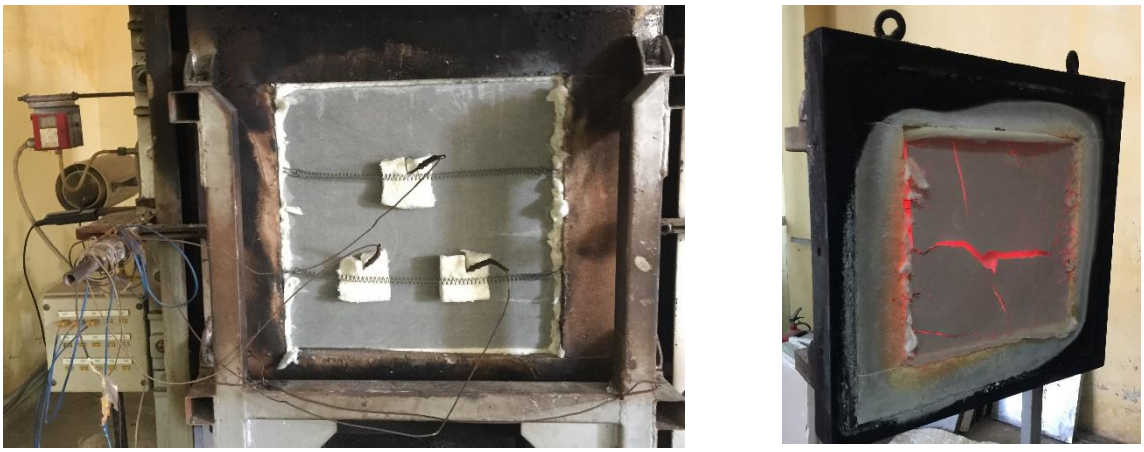


Figure 6: Test setup for determine the temperature of outer surface of specimen (left) and failure mode of surface inside oven after burning (right).

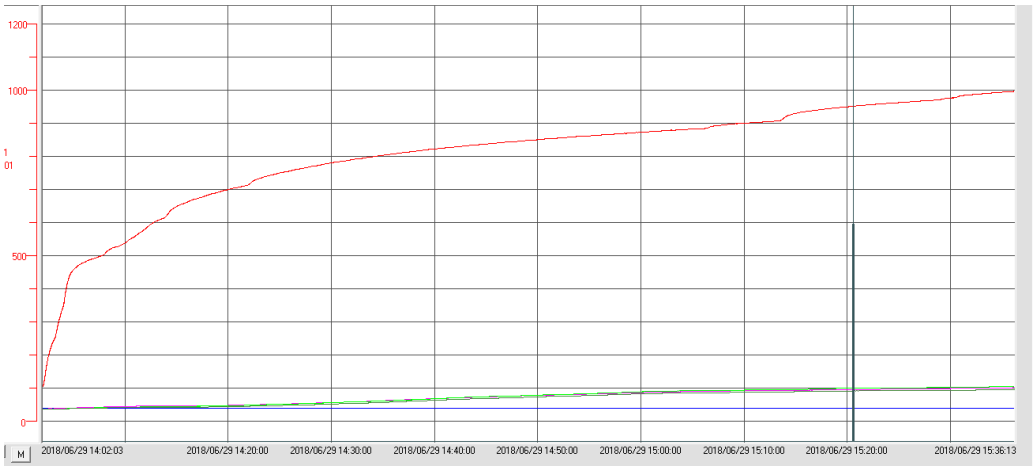


Figure 7: Temperature curves on the panel surfaces during fire resistant test; red curve: temperature on the surface inside oven, green curve: temperature on the surface outside oven.

Table 5: Temperature on the outside surface recorded by temperature sensors

Burning Time (min)	Real temperature (°C)	Temperature (°C)			
		Sensor 1	Sensor 2	Sensor 3	Average temperature (°C)
01	239	37.9	37.4	37.3	37.5
10	582.4	45.5	43.3	41.8	43.5
20	715.3	49.7	48.3	45.1	47.7
30	789.7	58.1	58.3	53.8	56.7
40	828.3	70.4	70.9	65.8	69.0
50	855	80	80.8	75.4	78.7
60	876.6	87.9	90.4	84.2	87.5
70	904.3	92.9	95	88.1	92.0
80	955	96.1	99.9	91.8	95.9
90	985.7	100	103	93.7	98.9

The test specimens for fire resistance with size of 60x480x480mm are firmly mounted to a frame. The test specimens should fully cover all the door of oven. A surface of the specimens is in contact with the flame, and 3 temperature sensors are placed on the other surface of the specimens (not in contact with the flame) as shown in Figure 6. The oven temperature is generated by LPG gas and simulated the increase of temperature typically of a fire, and the maximum temperature can reach 1000oC. The test is carried out in accordance with Vietnamese standard, TCVN 9311-1:2012 "Fire resistance testing – Element of Building Construction- Part 1: General Requirement" [5]. (this standard is the same as that of ISO 8034-2011). According to the above-mentioned standard, the specimens of 60mm thickness must be qualified with:

- The average temperature of the outside surface is not higher then 140ºC compared with the temperature of the real environment.
- The structure of the outside surface is protected from exposing by the fire.
- With the specimen of 60mm thickness, required time for not exposed by the fire must be 90 minutes maximum (normal standard).

Results of the test can be summarized as follows:

- After 90 minutes of max 985.7 ºC operation, the average temperature of the outside surface reaches 98.9ºC, and this recorded temperature is much lower than the allowable temperature, which is 140ºC higher than the temperature of environment.
- The outer surface of the specimens did not fail during the fire test.

The fire test shows that the Keramzit softcore sandwich panels meet all requirements of the Vietnamese standard as a fire-proof material. In addition to the recycling ability, the Keramzit panels do not generate toxic smoke during the fire, thus these sandwich panels are suitable for using as fire partition walls in building construction.

CONCLUSIONS

The paper presented the state-of-art on the properties and application of sandwich panels using the air cured PVA fiber cement sheets as skin layers in Vietnam. The use of Keramzit to develop the lightweight softcore as replacement of EPS for improvement the mechanical properties and fire resistance of EPS panels is described. The test results to determine the properties of Keramzit panels are reported. It has shown that the Keramzit panels using the local materials have superior properties to that of EPS panels, and they are suitable for use as partition walls of buildings.

ACKNOWLEDGMENT

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