The Effect of Pore Morphology on the Thermal Conductivity of Geopolymer Foam

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Abstract

Geopolymers are considered alternative to conventional cement recently. The use of fly ash and blast furnace slag in geopolymer, which are waste product considered as an environmentally friendly product due to the solution to the storage of wastes also. Geopolymer concrete production is also reported to be 44-64% less than the cement that causes the most CO_2 emissions. CO_2 emissions are reduced due to the minimum processed natural minerals and industrial waste products used in the geopolymer system. For this reason, this study comes to the fore in terms of the evaluation of wastes. Production of porous geopolymers are potential in use in many industrial application such as filtering, thermal insulation, light structural material, catalysis. By controlling the pore type, pore size distribution, pore connectivity and shape of porosities, potential usages are differentiated. In this study closed porosity geopolymer foams were produced by geopolymerization technique with the help of hydrogen peroxide and non ionic surfactants. The thermal conductivity, density and strength values was correlated with the changing pore size distribution depending on the amount of surfactant and foaming agent. We produced porous geopolymers with density values 450-500 kg/m^3, 0.12 W/mK thermal conductivity and 2.1 MPa strength value was prepared by this method. Interesting results will be reported.

Key words: Thermal conductivity, Geopolymer, Foam, Porosity, Surfactant

1. INTRODUCTION

The great acceleration seen in the construction sector in recent years and the necessity of the technically superior parameters and values of the construction materials to be used pave the way for the use and application of many new construction materials. Especially, the sustainability concept that arises due to the rapid consumption of fossil energy resources, air pollution caused by greenhouse gas, the effort to minimize the amount of energy use, and the lack of proper use of the produced materials accelerates the research and development of these materials [1]–[3].

Today, parallel to the increasing environmental awareness, national and international environmental policies are becoming more stringent. Kyoto Protocol has been signed by many countries and studies have been started to reduce CO_2 emissions. The World Business Council for Sustainable Development says it is responsible for the cement sector for about 5% of CO_2 emission. This is an indication that the cement sector has a significant impact on the increase in CO_2 emissions. [4]. The concrete and cement sector has been criticized for not only high emissions of carbon dioxide, but also consuming large amounts of natural resources and energy for the, mainly from cement production. These justified criticisms are tried to be overcome by alternative solutions. With the addition of fly ash, industrial waste in cement based systems (such as plaster, mortar, concrete), can be minimized and carbon dioxide emission can be minimized and the need for natural resources is reduced [5]–[12].

In our country, resources such as petroleum, coal and natural gas are used for energy production. As presented in TÜİK 2015 and 2016 reports, coal use for energy production is expected to increase gradually by 2040 [13], [14]. This means that by-products such as fly ash formed as a result of combustion of coal will also increase gradually. While Japan recycled 96% of fly ash in the context of cyclic economy and England, India, America, Australia recycles about 50% of the fly ash, this ratio remains 15% in Turkey [14]. One of the other objectives of this study is the fact that the fly ash, which is generated as a waste of millions of tons per year, can be converted into products.

Secondly, energy efficiency in buildings is always an important issue. Demand for energy, which is indispensable for human life, is increasing rapidly with population growth, industrialization and urbanization. Meeting the increasing energy consumption in the world where there is limited energy supply has been a problem for many countries and the dependence on foreign energy has increased [18]. In Turkey, a large part of the energy consumption consists of housing under the name of city consumption. Heat insulation is one of the most important measures that can be taken in order to ensure energy efficiency in houses.

Thermal insulation materials used in buildings are the most effective solution in reducing heat losses. In this way, it contributes to the almost zero energy target by reducing the heat energy requirement in buildings [11]. This study was carried out on the development of porous geopolymer wall elements for insulation. This study gains importance in CO_2 emission, cyclic economy, and energy fields thanks to the reduction of cement use, recycling of fly ash and the development of thermally insulated wall elements.

2. Materials and Methods

The mix composition of foam geopolymer include fly ash, metakaolin, sodium hydroxide, sodium silicate, expanded perlite, water and chopped polypropylene fiber (Table 1). Hydrogen peroxide was used as a foaming agent (%35) and foam stabilizer was used to obtain foam stabilization. Fly ash (FA) was taken from the Seyitömer Thermal Power Station Turkey and metakaolin (MEFISTO L05) was supplied from Czech Republic. Chemical compositions of metakaolin and fly ash are presented Table 2.

The principle of homogeneous mixing of solid components and liquid components in separate places was followed. First, the NaOH flakes were completely dissolved in water to obtaion 10M environment and then mixed with sodium silicate solution. Geopolymer slurry was added by adding alkaline solution to the mixture of metakaolin, fly ash, exploded perlite and polypropylene fibers mixed separately. After the geopolymer slurry became homogeneous, foaming agent and foam stabilizer were added and mixed. Finally, foam mixture was poured into 100x100x100mm molds and cured at 60°C.

Table 1. Composition of foam geopolymer mixtures

Code	Fly Ash	MK*	FS*	Perlite	Fiber
1	90	10	%0,15	%0	0,21
2				%2	
2				%4	
4				%8	
5	90	10	%0,45	%0	0,21
6				%2	
7				%4	
8				%8	
9	90	10	%0,75	%0	0,21
10				%2	
11				%4	
12				%8	

(*MK means metakaolin and FS means Foam Stabilizer)

Table 2. Chemical content of Fly ash and Metakaolin

	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O
Fly Ash	50,30	19,10	4,55	12,40	4,67	2,16
Metakaolin	54,10	41,10	0,13	1,10	0,18	0,80

The compressive strength tests were conducted with a compressive testing machine on the samples whose dimensions were 100 × 100 × 100 mm with 50 kN/mm^2 loading speed. Compressive strength test was applied after drying the unmolded samples were stored in the laboratory conditions for 28 days. The thermal conductivity coefficient λ was calculated with modified transient plane source. The bulk density of the product was calculated as a ratio of the mass to the volume of the sample.

3. Results and Discussion

Table 3 presents characteristics of geopolymer foam samples such as density, thermal conductivity and compressive strength. The compressive strength and the value of the heat conductivity coefficient were dependent on the foam stabilizer amount and hence the pore size of the obtained geopolymer foams.

Table 3. Experimental results of geopolymer foam samples

Code	Density kg/m^3	CS* N/mm^2	TC* W/mK	PD* µm
1	448	1816	0.079	928.5
2		1824		
2		1189		
4		1011		
5	454	1831	0.082	659.5
6		1683		
7		1372		
8		1225		
9	460	2145	0.092	573.5
10		1504		
11		1242		
12		925		

(*CS means compressive strength, TC means Thermal Conductiviy and PD means Pore Diameter)

According to scanning electron microscopy analysis it is observed that samples have closed porosity, pore morpholgy is pretty homogeneous and pore dimensions getting smaller in accordance with foam stabilizer amount (Figure 1). The samples contain 0.15%, 0.45% and 0.75% foam stabilizer, respectively and pore dimensions are 928.8µm, 659.5µm and 573.5µm.

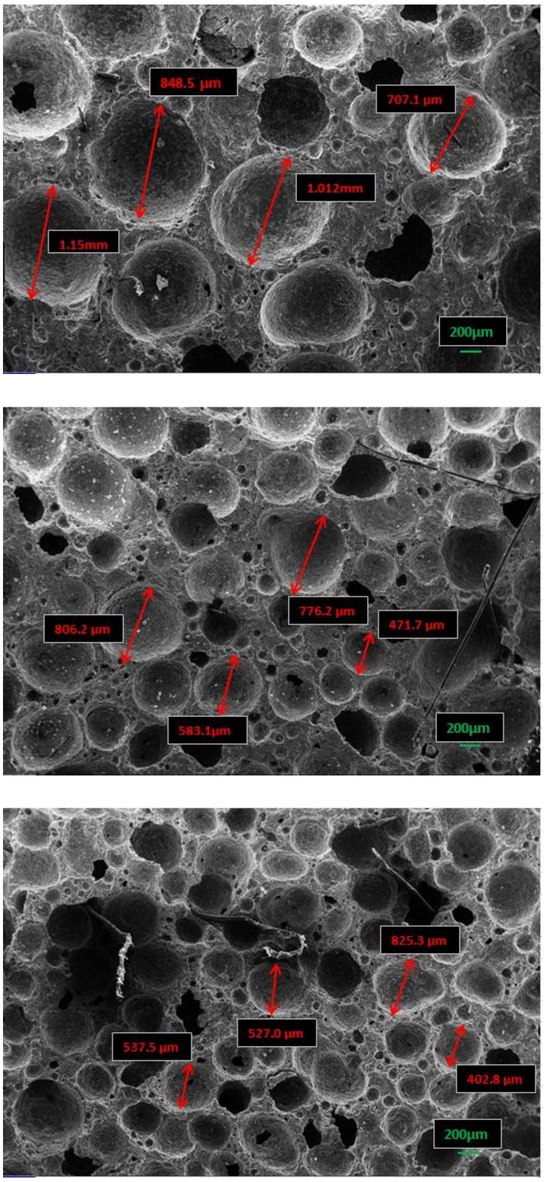

Figure 1. Scanning electron microscopy images of geopolymer foams at 50X magnification. Foams contains %0.15, %0.45 and %0.75 foam stabilizer respectively.

The results of bulk density of geopolymer foams are shown in Table 3. No significant differences were observed in their density as a constant amount of hydrogen peroxide was used in the production of foam geopolymer. Due to the increase in the amount of perlite and the volume of geopolymer slurry, overflows occurred during foaming. Small variations in density values can therefore be attributed.

The compressive strength was obtained from an average of three cubic specimens with dimensions of 100×100×100 mm cured during 28 days were tested. The results of compressive strength of geopolymer foams are shown in Table 3. It was observed that the perlite-free foams had higher strength values compared to the samples containing 8% perlite. This situation is attributed to the lack of bonding between perlite and geopolymer foam.

Table 3 presents the thermal conductivity performances of geopolymer mixtures. Thermal conductivity tests was carried out on all twelve geopolymer mixtures. However, since there are fluctuations in thermal conductivity values, average values are given for three different foam stabilizer groups. It was observed that thermal conductivity value increased with increasing amount of foam stabilizer and decreased pore size. As the pore size decreases, the insulating property is expected to improve. but in this study it was observed that conductivity increased. This result is attributed to the variability of the density value.

4. Conclusion

According to this study, it is possible to produce 500 grade foam geopolymer (450-550 kg/m^3). The presence of perlite as an aggregate gives the material better insulating properties but it also decreases compressive strength. Increased foam stabilizer reduces pore size and hence increases thermal conductivity. Although the shrinkage of the pores increases the strength values, optimum values should be found to maintain both properties as the thermal conductivity values deteriorate.

The result show that hydogen peroxide with foam stabilizer is effective in obtaining homogeneous pore morphology with low thermal conductivity. Geopolymer mixtures where the amount of perlite is maximum 2% appear to meet the values specified in TSE 13655 (> 1.5MPa, d <450-550kg/m^3 and ϰ <0.12W / mK).

5. References

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6. ACKNOWLEDGEMENTS

This work was financally supported by Afyon Kocatepe University under the contract of 19.Fen.Bil.01 BAP Project and also it is supported by TUBİTAK project 218M778.