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Investigation Of The Availability Of Vermiculite In Thermal Insulation Technologies

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ÖZET

Bu makale duvarlardaki farklı yalıtım malzemelerinin karşılaştırmalı teorik ısı transferi çalışmasını sunmaktadır. Çalışma için seçilen malzemeler aerojel, taşyünü, cam yünü, koyun yünü, kenevir, keten, cüruf yünü, cam elyaf, fenolik köpük, vermikülit, PUF / PIR köpük, polistiren köpük, talaş, perlit, polyester, karton ve mantardır. Bu çalışmada, çimentolu sıva, kırmızı tuğla / uçucu tuğla, çimento sıva, kontrplak, yalıtım malzemesi tabakası ve alçıpan çok tabakalı, yani farklı yalıtım malzemeleri ile değişen beşinci tabakalar hariç tüm tabakaların aynı olduğu altı tabaka kombinasyonu tanıtılmıştır. Çalışmadan, tuğla duvarın kırmızı tuğla duvardan daha düşük ısı transferine sahip olmasına rağmen, yalıtım katmanı olmayan kırmızı tuğla duvar ve uçucu tuğla duvarın daha yüksek ısı transferine sahip olduğu sonucuna varılabilir. Kırmızı tuğla duvar söz konusu olduğunda, aerojelli duvar en düşük ısı transferine sahiptir ve 100C'de 2.53 W ve 300C'de 7.60 W ve vermikülitli duvar 100C'de 9.28 W ve 27.83at 300C'de en yüksek ısı transferine sahiptir. Uçucu tuğla durumunda, aerojelli duvarın en düşük ısı transferi 100C'de 2.43 W ve 300C'de 7.28 W'dir ve vermikülitli duvar 100C'de 7.97 W ve 300C'de 23.91 W olan en yüksek ısı transferine sahiptir.

Anahtar Kelimeler: Isı yalıtımı, ısı verimliliği, kırmızı tuğla

ABSTRACT

Buildings are aimed to provide shelter against the weather and climatic vagaries but at the same time a good building construction should provide thermal comfort in an energy efficient way. One of the major components of building envelope is walls which plays an important part in heat transfer. If thermal resistance of walls is high the indoor environment can be maintained at desired levels of temperature with minimum energy requirements. In order to improve the building thermal efficiency it is important to improve the thermal resistance of the walls through use of suitable insulating materials. This paper presents a comparative theoretical heat transfer study of different insulating materials in walls. The materials chosen for study are aerogel, rockwool, glass wool, sheep wool, hemp, flax, slag wool, fiber glass, phenolic foam, vermiculite, PUF/PIR foam, polystyrene foam, sawdust, perlite, polyester, cardboard and cork. Present study introduced multilayer of cement plaster, red brick/flyash brick, cement plaster, plywood, insulating material layer and gypsum board i.e. six layers combination have been introduced in which all layers are same except fifth layers which is varied by different insulating materials. From the study, it can be concluded that red brick wall and flyash brick wall without insulating layer has higher heat transfer although flyash brick wall has lower heat transfer than red brick wall. In case of red brick wall, wall with aerogel has the lowest heat transfer and it is 2.53 W at 100C and 7.60 W at 300C and wall with vermiculite has highest heat transfer which is 9.28 W at 100C and 27.83at 300C. In case of flyash brick, wall with aerogel has lowest heat transfer which is 2.43 W at 100C and 7.28 W at 300C and wall with vermiculite has highest heat transfer which is 7.97 W at 100C and 23.91 W at 300C.

Keywords: Thermal insulation, thermal efficiency, red brick

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1. INTRODUCTION

Vermiculite is the name of a group of 2.1 phyllosilicate minerals composed of hydrated magnesium-aluminium-iron sheet silicates, which contain water molecules within their layered structure (Walker, 1961, Grim, 1968). They are made of one octahedral sheet lies in between two tetrahedral sheets (Velde, 1992). When heated rapidly to between 870 and 1100 °C, the interlayer water is turned to steam and the pressure generated within the structure disrupts the vermiculite silicate layer by a process known as exfoliation (Obut and Girgin, 2002, Marcos and Rodríguez, 2010a). Because of this process, its volume expands to more than eight times that of the unprocessed crude (Justo et al., 1989, Basset, 1963). Exfoliated vermiculite is lightweight with thermo-insulating properties. It is also highly porous, insoluble in water and organic solvent, non-toxic and has good absorption properties (Suquet et al., 1991, Mysore et al., 2005). These physical properties enable its use across a wide range of applications (Muiambo et al., 2010, Mouzdahir et al., 2009, Bergaya et al., 2006). Due to its poor transfer of thermal energy, vermiculite has a low specific heat capacity and therefore requires a significant amount of energy (greater than 1GJ/t) for its exfoliation (Torbed Service Limited., 1997, Andronova, 2007). The highenergy requirement for its exfoliation using either rotary or vertical furnaces fuelled by oil or natural gas is one of the problems limiting the industrial processing of vermiculite using conventional thermal methodology. Apart from the high consumption, other limitations of the of the conventional method of exfoliation are large space requirements, emission of hazardous gases such as carbon monoxide (CO); carbon dioxide (CO2); oxides of nitrogen (NOX) and oxides of sulphur (SOX), massive emissions of dust and particulate matter (PM < 10 µm), poor process control, and over reliance on fossil fuels. The products also come out at very high temperature (700 °C) and take several hours to cool down. This slows down the marketing and distribution process (Strand and Stewart, 1983, Marinshaw, 1995). Therefore, this is a process with several challenges and opportunities for improvement.

Raw vermiculite is characterised into five different grades (micron, superfine, fine, medium and large grades) according to their different particle sizes range. The different grades and the associated particle size and bulk density of raw vermiculite are given in the Table 1 . It shows that the size of all the vermiculite grades range from 0.250 to 8.00 mm while the loose bulk density varies between 700-1050 mm.

Table 1. The different raw vermiculite grades, particle size distribution and bulk density for Palabora vermiculite (Palabora Europe., 2009, The Vermiculite Association, 2011)

Grade	Raw vermiculite		Exfoliated vermiculite	
	Particle size distribution (mm)	Loose bulk density (kg/m³)	Product bulk density (kg/m³)	Specific surface area (m²/g)
Micron	0.250-0.710	700-850	90-160	6.4
Superfine	0.355-1.000	800-950	80-144	5.4
Fine	0.710-2.000	850-1050	75-112	4.4
Medium	1.40-4.00	850-1050	72-90	4.0
Large	2.80-8.00	850-1050	64-85	3.8

With increase in population and urbanization, past few decades have seen rise in buildings to provide more space and accommodate more, keeping the cost low. In all these efforts the thermal comfort of a building has become more dependent on electro-mechanical devices. The electricity consumption of buildings is rising at a fast pace thus it becomes necessary to use new techniques for enhancing thermal comfort in buildings in India. Building envelope in itself can act as a major determinant in improving thermal comfort if proper passive measures are adopted. Raman et. al. describe the development of a solar passive system which can provide thermal comfort throughout the year in composite climates. Two passive models have been studied, passive model 1 comprising of two sets of solar chimney and in passive model 2 both trombe wall and sack cloth cooling concepts were incorporated . I.L. Wong et al discussed transparent insulation system for building applications, drawbacks to previous applications, cost trends and analysis of the limitation in information from previous studies . D. H. W. Li and S. L. Wong investigated the shading effects due to nearby obstruction when day lighting schemes are being employed [3].

S. Chungloo and B. Limmeechokchai studied the benefits of application of solar chimney on the south roof and cool metal ceiling on the north roof through the experiment in a detached building called a controlled cell, and a related numerical model has been constructed from computational fluid dynamics (CFD) program.

R. V. Ralegaonkar and R. Gupta reviewed intelligent building construction with the aid of passive solar architecture approach, which makes use of specific building design principles and reduces the artificial energy requirements for achieving indoor thermal comfort . M. A. Kamal reviewed and analyzed various passive cooling techniques and their role in providing thermal comfort and its significance in energy conservation . N. B. Geetha and R. Velraj reviewed the various possible methods of passive cooling for buildings and discussed the representative applications of each method . By applying layers of high performance insulation on wall of building thermal comfort in building with low energy consumption can be achieved. Xiaolu Li et al. introduced lightweight steel structure residential housing which has the property of green, energy saving, environmental protection. They analyzed and studied lightweight steel structure residential building in North America, Japan and Europe. Then according to particular condition in China, development status and properties are introduced in lightweight steel structure residential building, including some traditional housing concept, and intensive steel residential building. They introduced multilayer of latex, putty, gypsum board, rockwool, breathing proof paper, wooden, extruded plate, OSB rally edition and metal carved panels with light steel keel .

Laszlo Bax et al. introduced five solutions from chemical industry that can bring significant energy savings which are 1) reflective indoor coating 2) high reflectance and durable outdoor coating 3) phase change material (PCM) 4) new insulation foams 5) other insulation modules. According to them, advanced or new insulation foam can reduce energy cost for heating by 30%-80% .

Figure 1. (i) fiber glass, (ii) polystyrene, (iii) polyurethane foam

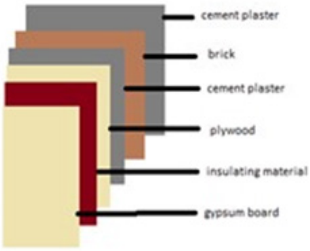

Figure 2. Multilayer wall with six layer of different materials

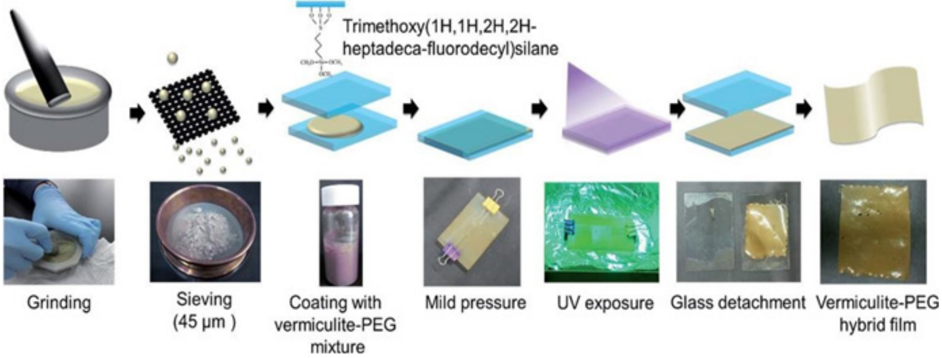

Figure 3. Schematic description and photographic images of the fabrication process of a vermiculite–PEG hybrid film.

2. APPLİCATİONS OF RAW AND EXFOLİATED VERMİCULİTE

Raw vermiculite has only limited applications such as, for circulation in drilling mud, fillers for fire-resistant wallboard and in the annealing of steel. Thus, the markets for un-exfoliated vermiculite are limited (Strand and Stewart, 1983). Figure 2. shows the raw and exfoliate form of medium grade vermiculite obtained from Brazil.

The bulk density of the processed crude vermiculite reduced from the range of 640 to 1120 kg/m3 to the range of 64 to 160 kg/m3 when exfoliated, depending on the retention time in the furnace, furnace temperature and the furnace efficiency. Mineralogy and the degree of alteration of the parent biotite and phlogopite also influence the degree of exfoliation (Kogel et al., 2006, Justo et al., 1989). The resulting lightweight material has low density, is chemically inert and has a highly porous structure together with exceptional thermal, acoustic, adsorbent and fire resistant properties (Marcos et al., 2009, Muiambo et al., 2010, The Vermiculite Association, 2011, Obut and Girgin, 2002). These properties make vermiculite suitable to be widely used for various industrial applications, such as in the construction, agriculture, horticulture, medicine and cosmetic industries (Muiambo et al., 2010, The Vermiculite Association, 2011, Bergaya et al., 2006).

Figure 4. The raw and exfoliated form of medium grade of Brazilian vermiculite

3. VERMİCULİTE STRUCTURE AND CHEMİCAL COMPOSİTİON

Vermiculite minerals are formed through the hydration of either biotite or phlogopite under the influence of weathering or hydrothermal alteration (Basset, 1963, Grim, 1968). This process involves the alteration of the parent biotite or phlogopite by the reaction of hydrothermal fluid (mostly hot water). During this process of vermiculite formation from mica minerals (biotite and phlogopite), which are bound together by strong assemblage of bonds and have low moisture content, there is a slight rearrangement of the atoms (cationic exchange) within the crystal lattice layers followed by the introduction of water molecules into the interlayer space (Bergaya et al., 2006). The interlayer potassium ions (K+) of the parent mica are replaced by other cations such as Mg2+, or combination of Mg2+ and Ca2+ ions. Vermiculite produced from this process has hydrated interlayer space and is bound together by a weak Van der Walls bonds. The weaker bond and presence of water in vermiculite interlayer space causes its ability to swell and exfoliate. Following is the general molecular formula for trioctahedral vermiculite (Grim, 1968, Bergaya et al., 2006, Deer et al., 1966).

4. INTERSTRATİFİCATİON İN VERMİCULİTE

The extensive work by Weaver (1956) on 6000 clay mineral samples revealed that about 70% of the samples are mixed–layered or have interstratification of two or more different clay minerals and are therefore not pure vermiculite. Interstratified phyllosilicates are clay mineral compositions made up of two or more different components stacked together along the unit cell (Grim, 1968, Bergaya et al., 2006, Essington, 2004). The interstratification may be regular or irregular. In regular stratification, the stacking of two or more clay minerals follows a regular or periodic repetition (example: chlorite-vermiculite) while the stacking is not well ordered in irregular stratification (example: illite-chlorite). There is possibility that mixed layer interstratifications of clay minerals may have significant importance on its applications and engineering processing because this has a significant influence on its structure and physical properties, such as layer charge, moisture content and exfoliation property (Bergaya et al., 2006, Grim, 1968).

5. WORLD VERMİCULİTE PRODUCTİON AND APPLİCATİONS

The major world primary deposits of vermiculite are in USA, South Africa, Zimbabwe, Russia, Australia, China and Brazil (Elliot, 2011). The annual production of vermiculite is estimated to be 570 tonnes in 2012, and the global vermiculite reserves were estimated to be 60 million tonnes (tanner, 2013). The global vermiculite production from 2000 to 2011 is shown , with South Africa having the highest production from 2000-2011. The figure excludes production by countries for which data are not available while the total productions for Argentina, Australia, Bulgaria, Egypt, India, Japan and Uganda are grouped as others (Brown et al., 2013, tanner, 2013, Cordier, 2010). The price of vermiculite varies with factors such as applications, size grade, source of raw vermiculite and demand (Elliot, 2011).

6. CONCLUSİONS

Vermiculite has been adopted as a general name for minerals that exhibit exfoliation property. Most of these minerals are not pure vermiculite, but are mixed layer vermiculite-mica and they possess distinct physical and chemical properties, which vary in different vermiculite samples. The variations in the geochemistry of vermiculite samples obtained from different geological locations may be due to the different mode of formations, primary mica minerals and stages of alteration.

These influence the behaviour of the different vermiculite samples when undergoing exfoliation.

Water networks have been described as the major factor that gives vermiculite its exfoliating property and hence as minerals of high industrial and economic values. Chlorite minerals that have the same chemical composition as vermiculite, but no interlayer water do not expand like vermiculite. The water content in vermiculite is characterised as free water, bound water, and high temperature hydroxyl water as a function of the temperature required for their removal from the vermiculite structure. Vermiculite is a 2.1 phyllosilicate clay mineral that has been used for many decades in the expanded form for agriculture and horticulture, construction, insulation and for other industrial applications such as for drilling mud, paints and brake pads. Vermiculite expansion occurs when the trapped interlayer water molecules within the structure are rapidly heated at high temperatures of between 870-1100 °C leading to the mechanical separation of the silicate layers. A critical literature review in the field of vermiculite processing has shown that chemical and conventional thermal exfoliation techniques are the two prominent exfoliation methodologies. The chemical exfoliation method uses chemicals such as $H2O2$ and weak electrolytes. This exfoliation method is limited to laboratory scale and there are no reports of such techniques being used for exfoliation at a commercial level. Despite being the state of the art the industrial thermal exfoliation of vermiculite by oil and gas furnaces is unsustainable for vermiculite processing due to high environmental impact, large energy requirement (greater than 1 GJ/t), poor process control, and emissions of dust and particulate matter ($PM<10\mu m$).

Due to the sustainability limitations of both chemical and conventional methods of vermiculite exfoliation, some researchers have employed the selective heating advantage of microwave energy for vermiculite exfoliation. The little body of published work which considers the application of microwave energy for vermiculite exfoliation has typically focused on the use of domestic microwave ovens (2.45 GHz, power below 1200 W), which produce heterogeneous distributions of electric field and uneven heating of the feedstock due to the creation of multiple hotspots and low power density. Few attempts have ever been made to scale up microwave processing of vermiculite and there are no previous reports of a continuous high electric field based vermiculite exfoliation system at microwave energy inputs of greater than 15 kW. This may be due to the little attention given to understanding the interaction of microwave energy with such minerals.

7. DİSCUSSİON

The throughput of raw vermiculite moving through the applicator determines the bed depth, interacting mass and the volume of material in the applicator as does the belt speed. For the pilot scale system, the throughput of the vermiculite was varied by using a vibratory feeder, which allows control over the feedstock bed depth when combined with a moving belt conveyor.

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