

Sawdust based core material for eco-friendly Vacuum Insulation Panels (VIPs)

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ABSTRACT

This study presents an alternative core material developed by using waste sawdust powder for eco-friendly Vacuum Insulation Panels (VIPs). This alternative VIP core material was prepared by using locally sourced waste sawdust powder from woodwork industry. Three samples containing varying mass ratios of sawdust and fumed silica were characterized in terms porosity, pore size, density and thermal conductivity. VIP samples of size 150 × 150 mm were prepared using new alternative core material at a pressure of 0.5 mbar. Center of panel thermal conductivity values of VIP samples were measured just after manufacturing and after storing seven days at room temperature. Test results showed that thermal conductivity (center of panel) values increased with higher contents of sawdust in the VIP core. Reducing sawdust mass% in the VIP core sample from 85% to 30% led to approximately 73% decrease in VIP center of panel thermal conductivity from 21.12 mW/mK to 5.52 mW/mK. Thermal conductivity (center of panel) of VIPs containing 30% sawdust, 55% fumed silica and 15% SiC was measured to be 5.52 mW/mK, which is comparable to commercially available fume silica VIPs. Thermal conductivity results show that sawdust powder in VIP core offers a potentially low cost eco-friendly alternative core material by partially replacing fumed silica, the dominant contributor to the VIP environmental impact.

KEYWORDS

Vacuum Insulation Panel, Core material, Sawdust powder, Fumed silica, Thermal conductivity

INTRODUCTION

Vacuum Insulation Panel (VIP), a high thermal performance insulation, is made of inner core board sealed in outer high barrier envelope under vacuum conditions. VIP core is made from porous material retains the vacuum below certain threshold level and physically supports the VIP envelope (Alam et al., 2011). Gaseous heat transfer is suppressed within the core using small size porous materials such as fumed silica. However, fumed silica currently used in the VIP core is an expensive material and have higher associated environmental impact. Global Warming Potential (GWP) of a specified VIP (size 1 m², thickness 25 mm and weight 4.5 kg) at production stage is declared as 42.40 kgCO₂eq of which 95-99% is contributed by the VIP core (Porextherm Dämmstoffe GmbH, 2014). Among the core materials fumed silica is responsible for at least 90% of the environment impact (Porextherm Dämmstoffe GmbH, 2014). VIP cost and environmental impact reduction can be achieved by fully or partially replacing fumed silica in core board with cheaper natural or renewable alternative materials. Sawdust waste powder is one of the alternative materials which can possibly be incorporated in VIP core as a partial replacement of fumed silica for producing eco-friendly low cost VIPs.

Sawdust is an organic material obtained as waste by-product of the activities of woodworking such as milling, sawing and sanding in wood /furniture industry. Depending upon the nature of

woodworking activity, sawdust can be obtained in different forms and sizes including in the form of very fine powder. It has been used previously for applications such as lightweight cement aggregate (Ahmed et al., 2018) and thermal insulation (Lakraflı et al., 2013) because of its low bulk density, low thermal conductivity and higher porosity. These suitable thermo-physical properties make sawdust an appropriate candidate for VIP core material. This paper presents the development and testing of sawdust and fumed silica composite as VIP core material. The main aim of this work is to optimise thermal and physical properties of sawdust-fumed silica composite as a low cost eco-friendly VIP core material allowing effective recycling of sawdust waste originating from the woodworking industry.

MATERIALS & METHODS

For this study composites with variable mass ratios of fine sawdust powder, fumed silica and SiC (opacifier) materials were developed by dry mixing. Details of material constituent of different samples are shown in table 1.

Table 1. Composition of different investigated samples

Sample	Composition (mass %)		
	Fumed Silica	Sawdust	Silicon Carbide (SiC)
1	0	85	15
2	40	45	15
3	55	30	15

Sawdust used in the study was sourced from a local woodwork company originated as a waste by-product from the sanding operation of reclaimed pine wood. Sawdust waste powder was measured to have the following properties; thermal conductivity 48.68 - 64.08 mW/mK in the temperature range of 10 - 70°C, porosity 79.8%, average pore diameter 7.56µm and bulk density 286 kg/m³. Porosity, pore size and density were measured using Mercury Intrusion Porosimetry (MIP) method. VIP samples of size 150 × 150 mm were manufactured with new alternative core materials at a pressure of 0.5 mbar in the vacuum sealing chamber. Center of panel thermal conductivity of developed VIP samples was measured using Heat Flow Meter (HFM 446 Lambda Series- based on ASTM C518).

RESULTS & DISCUSSION

Pore size and gaseous thermal conductivity

Three samples 1, 2, and 3 detailed in table 1 were used for MIP measurement. Results of the porosity, average pore size and bulk density are shown in the table 2.

Table 2. Results of MIP measurement

Sample	Average pore diameter × 10 ⁻⁶ (m)	Porosity (%)	Bulk density (kg/m ³)
1	4.100	79.2	335
2	0.239	93.0	116
3	0.237	93.0	91

MIP measurements show that sample 1, no fumed silica, mainly comprising of the sawdust, had the lowest porosity of about 80% and the highest bulk density of 335 kg/m³. In composite samples 2 and 3, decreasing the sawdust contents to 45 mass% and 30 mass% led to increase in porosity to 93% and decrease in bulk density to 116 kg/m³ and 91 kg/m³ respectively. The

average pore diameter in sample 1 comprising mainly of sawdust powder was 4.1 μ m while for the composite samples containing both sawdust and fumed silica these values were in the range of 237-239 nm. Using the pore size data (table 1) in equation 1 gaseous thermal conductivity (λ_G) was calculated.

$$\lambda_G = \lambda_0 / ((1 + (0.032/P\Phi))) \quad (1)$$

Where (λ_0) is the thermal conductivity of air at atmospheric pressure (W/mK), P is the pressure (Pa) and Φ is the pore size (m). Results shown in figure 1 suggests that with composite materials consisting of sawdust and fumed silica (sample 2 and 3) gaseous thermal conductivity can be suppressed to negligible levels below the pressures of 10 mbar while for sample 1 comprising mainly of sawdust powder lower pressures of at least below 0.1 mbar will be needed. In figure 1, curves for sample 2 and 3 are almost identical due to very small difference in their average pore size (table 2).

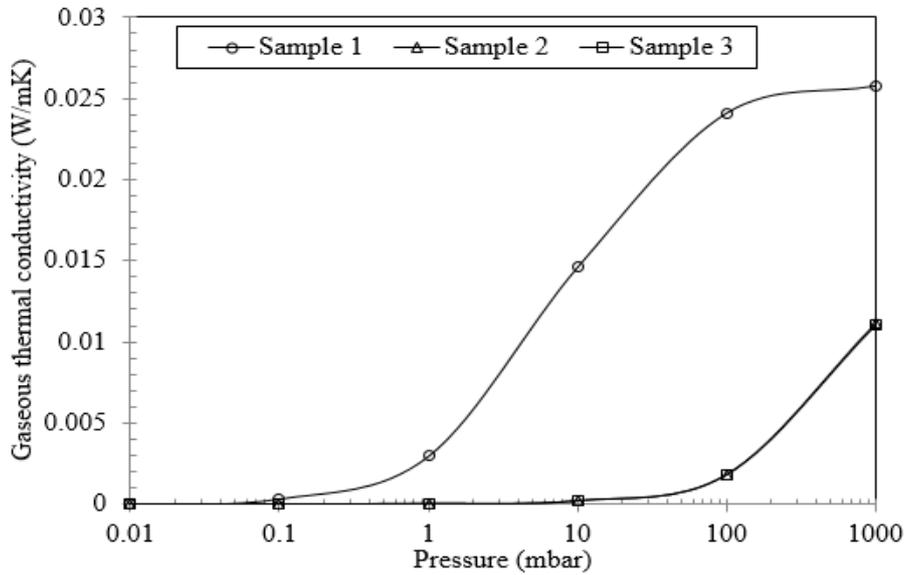


Figure 1. Gaseous thermal conductivity for sawdust and fumed silica composite samples as a function of pressure.

Thermal conductivity (Center of panel)

Results of experimentally measured center of panel thermal conductivities at mean temperature of 20°C of VIPs manufactured with samples 1-3 are shown in figure 2. Thermal conductivity values of VIP sample 1 (85% sawdust and 15% SiC) was measured to be 18.18 mW/mK rising to 21.12 mW/mK after 7 days at room conditions. For the VIP sample 2 (45% sawdust, 40% fumed silica and 15% SiC) was measured to be 6.22 mW/mK just after manufacturing increasing to 6.93 mW/mK after 7 days at room temperature. Reducing the sawdust content to 30% and increasing fumed silica content to 55% fumed silica in the sample 3 led to further decrease in the thermal conductivity to 5.10 mW/mK just after manufacturing going up to 5.52 mW/mK after 7 days at room temperature. Lower thermal conductivity of VIP samples can be attributed to the suppression of gaseous and radiative thermal conductivities due to a reduced smaller pore size (237-239nm) and presence of SiC opacifier respectively. The increasing trend of thermal conductivity after storing VIPs at room temperature is assumed to be due to increased pressure inside the VIPs because of outgassing from the sawdust and envelope material. Sawdust was obtained from the reclaimed pine wood which may potentially contain the residual adhesive from earlier use. This assumption was further reinforced from the results in figure 2

which show that the magnitude of thermal conductivity increase with time was found to be higher in samples containing higher mass % of sawdust powder.

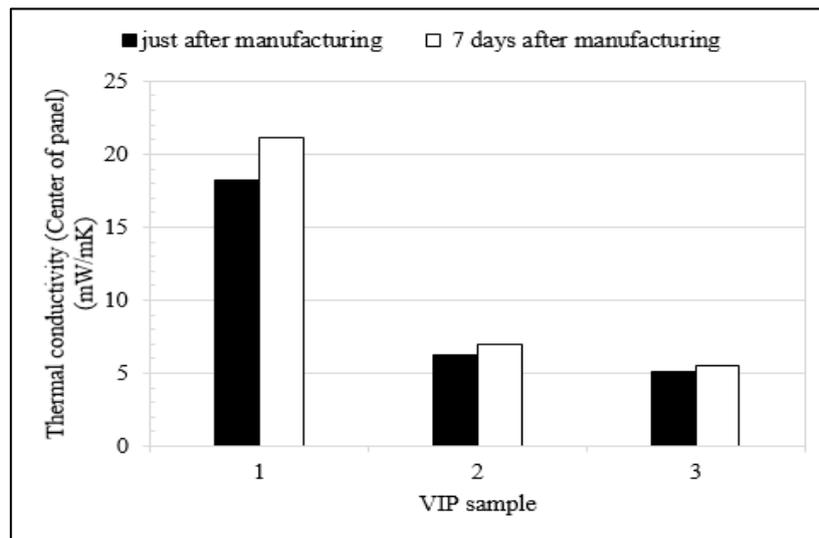


Figure 2. Experimentally measured thermal conductivity for VIP sample (1-3) with core material of sawdust and fumed silica composite

CONCLUSIONS

In this study application of waste sawdust powder in VIP core has been explored as an eco-friendly alternative core material to partially replace the expensive and high environmental impact fumed silica. Thermal conductivity measurement show the increasing sawdust contents in the sample led to higher thermal conductivity values. The lowest center of panel thermal conductivity value of 5.10 mW/mK was found for VIP sample containing 30 mass % of sawdust along with 55 mass% of fumed silica and 15% SiC which is comparable to that of center of panel thermal conductivity of commercially available fumed silica VIPs. After storing the VIPs at room temperature for 7 days, center of panel thermal conductivity value slightly increased to 5.52 mW/mK. Trend of increase in thermal conductivity with time was measured in all composite samples and attributed to outgassing from sawdust and envelope material. This aspect requires further investigation. It is also recommended to further evaluate the performance of composite materials under different climatic conditions to comprehensively ascertain the thermal performance for range of temperature and humidity conditions.

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