ALTERNATIVE CHEAP MATERIALS FOR BARRIER AND PROTECTIVE LAYERS OF VACUUM INSULATION PANELS (VIPs)

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ABSTRACT: *Vacuum Insulation Panels are among the most efficient insulation solutions nowadays. With thermal conductivity as low as 0.003 W/m.K, VIPs can be extremely beneficial for thermal insulation. VIPs consists of specially manufactured silica core having a very low thermal conductivity, which is provided with an external protective panel to protect the core from any possible damage or permeation of moisture into the core material which can increase the value of thermal conductivity. However, the only factor that puts a limit to VIPs' usage is higher cost than other insulations[1]. As VIPs are expensive, alternative materials that can be used for manufacturing VIPs were suggested and tested structurally and thermally. Hence the manufacturing costs can be reduced and VIPs can be ideal as well as economic means of insulation for green buildings.*

Key words: Alternative Materials, Cheap Insulation, Vacuum Insulation Panels, VIP, Insulation

1. INTRODUCTION

Vacuum Insulation Panel (VIP) consists of a porous core material covered by a vapour and air tight multilayer envelope as shown in Fig. 1 [2], which prevents any gas or moisture from the atmosphere to adsorb in the core[3], hence maintains its thermal insulation properties over time[4]. Pore structure is open to evacuate all the gas in the panel. Getters and desiccants are added to the core which absorb the vapours and gases that can otherwise adsorb in the core material[5]. Opacifiers are added to make the core opaque to infrared and hence reduce the radiative conductivity of VIP[6].

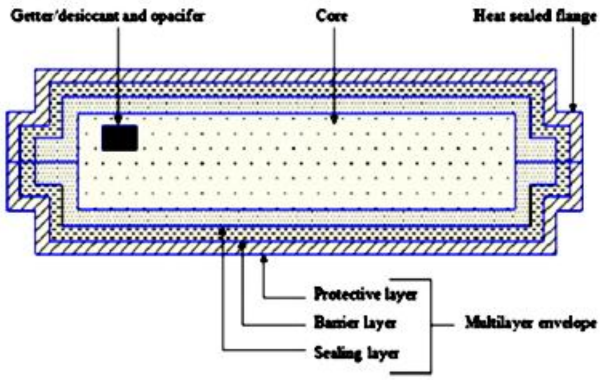

Figure 1 : Schematic of VIP

As far as costing is concerned, VIPs are expensive on account of the expensive materials used in barrier layers and protective layers. It is necessary to have these layers in a VIP as the vacuum is maintained this way which is the most important concern for VIPs. The commonly used barrier layer is single Aluminium foil that resists permeation. Aluminium is an expensive material but has excellent resistance to permeation. Similarly Protective Layer is usually made of Polyethylene Terephthalate (PET) that is also much expensive but has mechanical properties to serve as protective cover.

Therefore, in order to reduce cost of VIPs, alternative materials must be suggested for barrier and protective layers of VIPs that can compete in properties with the original materials. The cost reduction will make VIPs a very attractive solution for Insulating buildings is future.

2. ALTERNATIVE MATERIALS

Two materials, High-Density-Polyethylene (HDPE) for barrier layer and High-Impact-Polystyrene (HIPS) for protective layer have been investigated to serve as alternative materials. The VIP thus made of these new alternatives has been tested and results are obtained.

2.1 High-Density-Polyethylene (HDPE)

As for the barrier layer, the major concern is the permeation resistance value. HDPE provides excellent resistance for permeation of moisture as an alternative of Aluminium to be used in barrier layer of VIP. High-Density-Polyethylene (HDPE) is a thermoplastic polymer of polyethylene (PE). It has very long chains, with a molar mass usually between 2 to 6 million s. The longer chain provides transfer load more efficiently to the polymer structure by strengthening intermolecular interactions. This leads to a very tough material, with the most high impact strength among all the thermoplastics presently made. HDPE is a Class-I Vapour Retarder like Aluminium, with comparable resistance to moisture permeation. The properties of HDPE are given in Table 1.

Table 1 : Permeation Properties of Aluminium and HDPE

Properties	Aluminium	HDPE
Vapour Retarder Class	Class I	Class I
Permeation (US Perms)	0.05	0.06
Thermal Conductivity (W/m.K)	205	0.46

2.2 High-Impact-Polystyrene (HIPS)

Similarly for Protective layer, the major concern is to provide an outer protective covering to the panel. The HIPS or (High Impact) polystyrene is a polymer of PS obtained from styrene monomer, added to 5% - 15% of polybutadiene. The microscopic particles generated during the process transform properties of polystyrene, increasing impact resistance and stretching its capacity. Moreover, it also gets opaque and rigid, but is non-toxic. HIPS has an average Elastic Modulus of 2.15 Gpa, which can be easily related to that of PET (2.35 Gpa). Moreover, HIPS have also shows great thermal properties with a very low thermal conductivity (0.15 W/m.K) and can further contribute towards insulation when used in VIPs. The following are some of the properties of HIPS and its comparison with PET:

Table 2: Mechanical Properties of PET and H.I.P.S

Properties	PET	H.I.P.S
Elastic Modulus (GPa)	2.35	2.15
Density (kg/m^3)	1360	1040
Poisson's Ratio	0.43	0.46
Thermal Conductivity (W/m.K)	0.30	0.22

3. Physical Model

The physical model for the VIP roof x-section with suggested alternative materials is given as below. This model has been used to check the strength of both roof x-sections, namely the conventional VIP Insulated and VIP insulated with alternative materials. The only change is the use of alternative materials in Barrier and Protective layers of VIP. A uniformly distributed load (UDL) of 7980 N/m (as per testing standard according to testconsult.uk) has been applied on the roof top to check the possible deflections of roofs under load. The roof has been supported on both ends by brick walls. The said physical model has been depicted in Figure 2.

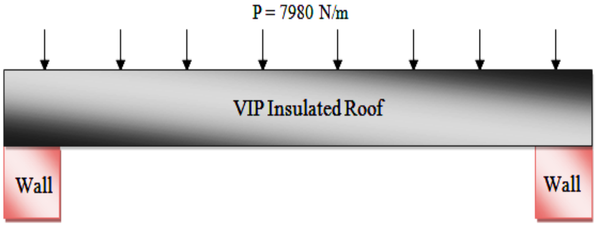

Figure 2 : Physical Model for Structural Analysis

4. Simulation

Once the alternative materials have been suggested and physical model has been defined, analysis has been made by using 'Static Structural Module in ANSYS Workbench'. Geometry comprising of basic layer-structure of roof was made for once and materials were defined on the basis of Elastic Modulus, Densities and Poisson's ratios. Once the geometry was complete, a fine mesh was generated and and the boundary conditions are subsequently applied.

For the conventional VIP x-section, the layers have been made and the conventional materials i.e Aluminium foil (Al foil) and polyethylene terephthalate (PET) have been defined for the barrier and protective layers respectively. Similarly, for the suggested VIP x-section with alternative materials, the layers have been made of suggested alternative materials i.e UHMWPE and High-Impact-Polystyrene (H.I.P.S) have been defined for the barrier and protective layers respectively. The solver has been run then and the following solutions had been obtained.

The strength of conventional VIP insulated roof x-section has been analyzed by evaluating the possible total deformation of roof along the vertical direction i.e. y-axis. The maximum deflection occurs at the centre of the roof and its value in meters comes out to be 9.2929e-5, or 93µm. The simulation result has been shown in Figure 3.

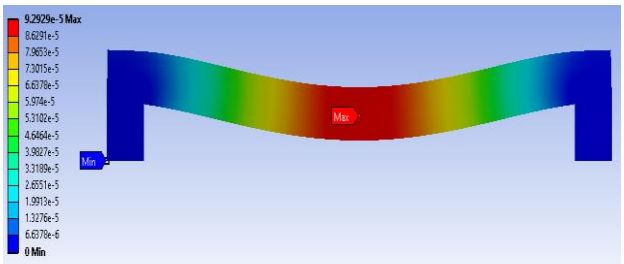

Figure 3: Simulation Result of Conventional VIP under Structural Load

Similarly, the strength of suggested VIP with alternative materials' roof x-section has been analyzed by evaluating the possible total deformation of this roof again along the vertical direction i.e. y-axis. The maximum deflection again occurs at the centre of the roof and its value in meters has been observed to be 9.7655e-5, or 97µm. The simulation result has been shown in Figure 4.

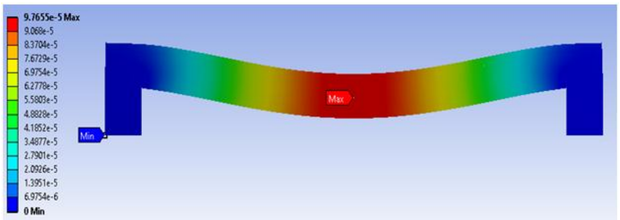

Figure 4 : Simulation Result of VIP with Alternative Materials

5. Validation

The validation of the said work has been done by using the theory of 'Composite Beams from the book Mechanics of Materials by RC. Hibbler, 8th Edition' (Chapter 6, Page 313). Relative Elastic Modulus of all the layers have been taken and using the relation from Simply Supported Beam under UDL, the maximum deflection has been estimated. It has been done by using the relations:

$$\frac{5WL3}{384EI}$$

Where E = Equivalent Elastic Modulus of Transformed composite beam, W = Total Load Applied, L= Length of Beam, I = Moment of Inertia of Transformed Beam.

Elastic Modulus of concrete has been taken as reference and the lengths of all other layers have been transformed accordingly. Using this composite beam approach and the relation for maximum deflection as given above, the result has been calculated for conventional VIP Roof and can be compared as follows:

Max. Deflection (Simulation Result) = 93µm.

Max. Deflection (Theoretical Result) = 91.4µm.

So there is a very small deviation from the exact value, the simulation has been validated.

3.6 Cost comparison of materials

As stated earlier in case statement, there is a great need of cost reduction is VIPs because it is almost the most attractive insulation means and the only shortcoming that limits the use of VIPs is its high cost. Therefore this study was aimed to suggest alternative materials that are low in cost as compared to conventional materials used in making

VIPs but have approximately the same properties as that of conventional materials. This will result in VIPs that are still efficient in insulation with a very little change in mechanical and thermal properties but are much cheaper as compared to conventional VIPs. This can possibly make VIPs the most desired insulation solution available in future.

Cost comparison of Aluminium and HDPE:

Average cost of Aluminium foil = 154.74/kg.

Average cost of Impermeable UHMWPE membrane = 35.028/kg.

Cost comparison of PET and H.I.P.S:

Average cost of PET Sheet = 192.58/kg.

Average cost of H.I.P.S Plastic Sheet = 72.52/kg.

6. VIP Price Comparison

A comparison has also been made among the prices of conventional VIP panels used and that of suggested VIP materials. The prices of materials have been taken from the data provided by the Punjab Works Department and the total price per square meter of the panel has been estimated. The reduction in cost comes out to be 36.7% which shows that how must cost efficient the alternative materials may prove to be and how a cheap VIP panel can contribute towards the energy demands in Pakistan.

Average Price of Conventional VIP Panel = Rs. $3666.78/m^2$.

Average Price of Suggested VIP with Alternative Materials = Rs. $2322/m^2$.

Reduction in cost = (3666.78-2322) / 3666.78
= 0.367 = 36.7%.

4. CONCLUSIONS:

The Vacuum Insulation panels (VIP) have thermal conductivity as low as 0.004 W/m.k and can greatly reduce energy requirements if employed in constructing building roofs. As VIPs are expensive, alternative materials that can be used for manufacturing VIPs were suggested and tested structurally and thermally. The structural and thermal simulation methods were validated later so that the methods described may be used for analyzing all cross-sections and VIPs (original and with alternative materials) and hence respective results were obtained and stated. Validations have been discussed separately and results are shown.

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