

## Functional Honeycomb Based Composite Panels for Structural and Thermal Management Applications

Zeyrek O, Demirural A and Baykara T\*

Mechanical Engineering Department, Faculty of Engineering, Doğuş University, Istanbul, Turkey

### Abstract

This study deals with the functional properties of honeycomb panels for structural applications, thermal management and sound/heat insulation to design more eco-friendly products. Using honeycomb panels filled with polyurethane (PU) and Phase Change Materials (PCM) led to fulfill desired properties such as minimum density, high stiffness, rigidity and strength and improved thermal properties and heat insulation. Mechanical responses of such panels were investigated along with thermal measurements. Functional roles in structural and thermal management applications may provide advantages such as low cost and high performance in housing, aerospace, automotive, packaging and transportation sectors.

**Keywords:** Honeycomb structure; Polymers; Composites; Mechanical properties

### Introduction

Sandwich panels with honeycomb structure are extensively used as effective, high performance lightweight structures. Honeycomb sandwich panels consist of two thin and hard surface sheets bonded to a thick and lightweight honeycomb structured core. Two parallel surface sheets provide flexural stiffness and strength while the honeycomb core supports the panel with its stiffness and also contribute to the shear stress acting on the panel. The core also provides flexural strength and out-of-plane shear and compressive strength of the panel. Honeycomb cores are made of aluminum, polymers, composites and natural fibers in the form of stiff and hard craft paper sheets [1].

Structural honeycomb cored sandwiches provide very high flexural stiffness with very low weights along with reduced cost. Sandwich honeycomb structured panels are also widely applied in many applications such as lightweight structural elements in buildings, furniture, packaging, transportation, aviation, space and automotive. Other than the structural performance, they also have advantages such as low cost, lightweight, practical mounting, eco-friendliness, recyclability and good acoustic insulation property.

Honeycomb structures made of natural fibers have distinct advantages over other core materials, aluminum, polymers and composites with lighter weight and lower cost. However, their mechanical properties are inferior to others. There is an ongoing innovation effort to develop new structures with novel functions along with low cost and high performance needs. Honeycomb structures have the advantage of open and large cell size to be filled by other materials for certain functions such as heat and sound insulation, vibration damping, thermal management and structural integration. Additional functional materials are filled into the cores in order to improve (such as polymeric foams) the targeted properties like sound absorption and others [1-6]. There is a huge challenge for effective use and storage of energy. Storing the energy in appropriate and practical forms is critical and effectively investigated all over the World. One of the most promising techniques of storing thermal energy is the application of PCMs (Phase Changing Materials). The basic principle in PCMs is the storage of latent heat which is based on the heat absorption or release when a materials undergoes a phase change from solid to liquid or liquid to gas or vice versa. A typical PCM, technical paraffins

are good latent heat storage materials due to its availability in a large temperature range [7-9].

Present study explores the competing demands of various functional inquiries expected from low cost, lightweight materials such as thermal management, structural integrity with rigid and stiff structure and vibration damping properties. Rigid honeycomb structures made of hard kraft paper were filled with polyurethane (PU) foam for vibration damping and sound insulation and also filled with Phase Change Materials (PCM) for thermal management purposes. Mechanical testing and thermal measurements were carried on the panels to characterize these functional properties.

### Materials and Method

#### Process

Hexagonal shaped sandwich honeycomb panels were formed with thin, rigid and stiff composite surfaces made of glass fiber reinforced polyester resins. The structural core panels for functional purposes are made with craft paper honeycombs with the open cells of 7-8 mm wide. Honeycomb craft paper was modified by impregnation with the polyester resin and dried. Such impregnation usually improves both the dry and wet strength and provides certain water-proofness to the structure. Honeycomb sheets then were mounted on the glass fiber composite thin surface layers. Following spraying the curing agent for the polyurethane, honeycomb cells were filled by the polyurethane foam using a specially designed needle assures a complete and faster filling cycle for each cells. As known, curing cycle has a strong impact on the thermal and mechanical behavior of thermosetting polymers. The extent of cross-linking which is a strong function of curing temperature and time is directly linked to the glass transition temperature (T<sub>g</sub>) of

\*Corresponding author: Tarik Baykara, Mechanical Engineering Department, Faculty of Engineering, Doğuş University, Istanbul, Turkey, Tel: +902164447997; E-mail: [tbaykara@dogus.edu.tr](mailto:tbaykara@dogus.edu.tr)

Received October 28, 2017; Accepted November 05, 2017; Published November 15, 2017

Citation: Zeyrek O, Demirural A, Baykara T (2017) Functional Honeycomb Based Composite Panels for Structural and Thermal Management Applications. J Material Sci Eng 6: 391. doi: [10.4172/2169-0022.1000391](https://doi.org/10.4172/2169-0022.1000391)

Copyright: © 2017 Zeyrek O, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

the thermosetting polymer. This transition temperature reflects the transformation of the polymer from glassy state to rubbery state, hence determines the applicability of the material at certain temperature with certain degree of safety and reliability. Hence assessment of  $T_g$  and its possible improvement is quite essential from material point of view. PU filled honeycomb structured composite panels with parallel composite rigid surfaces were conditioned at  $80^\circ\text{C}$  as the post curing process. In Figure 1, PU filled honeycomb sandwich panel is shown.

As for the second functional purposes, resin impregnated and dried honeycomb cells were filled with paraffin based phase change materials (PCM). Once again a specially designed filling apparatus assuring a smooth flow of PCM for a complete filling of each cell. Two glass fiber reinforced polyester resin thin composite layers were also applied for the construction of the functional panels.

### Mechanical testing

Flexural 3-point bending test were carried out on standard size samples (ASTM D 790 standards:  $15.5 \times 12.75 \times 192$  mm-w/h/l) extracted from the panel from different edges. The rate of loading was  $4.71$  mm/min (Figure 2).

### Thermal measurements

**The heating cycle tests:** Two separate identical cabins with dimensions of  $50 \times 50 \times 50$  cm were prepared for the thermal measurements. As one of them was used as the reference cabin without PCM, the inner walls of the other panel were mounted by the PCM filled honeycomb panels. The heating cycle tests were carried out using a homogeneous heat source for both of the cabin. Thermal cycle were initiated with identical rate of heating for both of the panel and the

temperature changes were recorded using a standard thermocouple and recording data logger (Figure 3).

Rate of heating and the heat absorption characteristics of the cabins were traced using a thermal camera focused on the central sections of the panels. Figure 4 shows a thermal imaging view of the PCM filled panel. Please note that white colored geometrical shapes represent the state of the PCM filled portion of the panel.

**The cooling cycle tests:** The cooling cycle tests were conducted using identical amount of dry ice bag located inside the cabins and the temperature changes were recorded using a standard thermocouple and recording data logger. The cabins were left to complete the cooling cycle until the whole dry ice inside melted completely and the temperature was reached back to the room temperature.

### Results

The 3-point bending test results are given in Figures 5a and 5b. The results reveal maximum flexural strains of  $0.042$  mm/mm for both tests and maximum flexural stresses,  $6.25$  MPa and  $13.10$  MPa.

Figure 6 shows the heating cycle test results on cabins covered



Figure 1: Honeycomb sandwich panels filled with PU.



Figure 2: Point bending test on the specimen extracted from the panel.



Figure 3: PCM filled  $40 \times 40$  cm polycarbonate panels inside the test cabin.

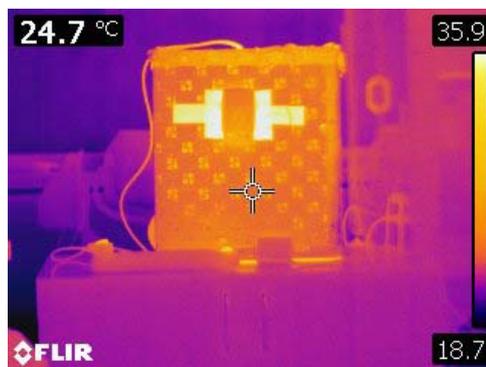


Figure 4: Thermal image of the PCM filled polycarbonate panel being tested with a heat source inside.

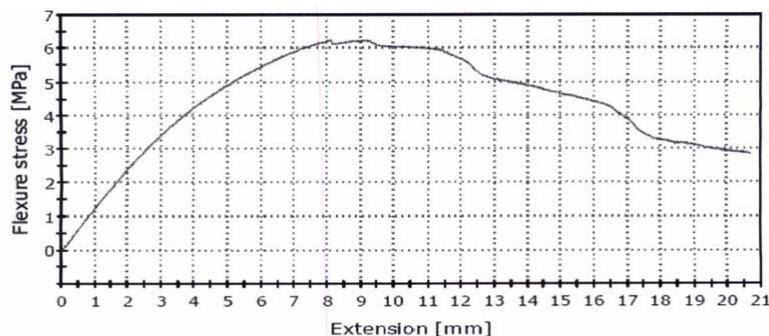


Figure 5a: 3-point bending graph of panel material.

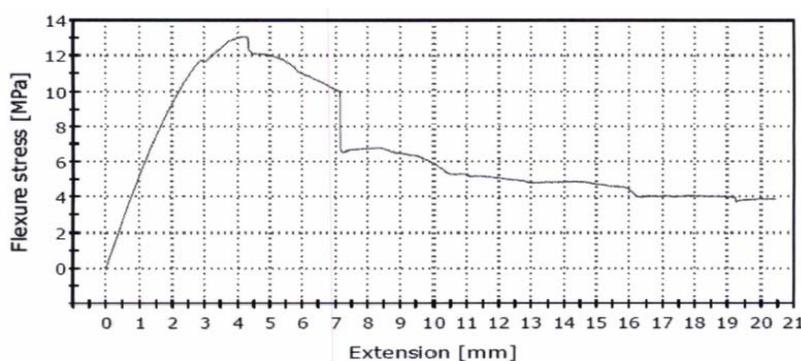


Figure 5b: 3-point bending graph of panel material.

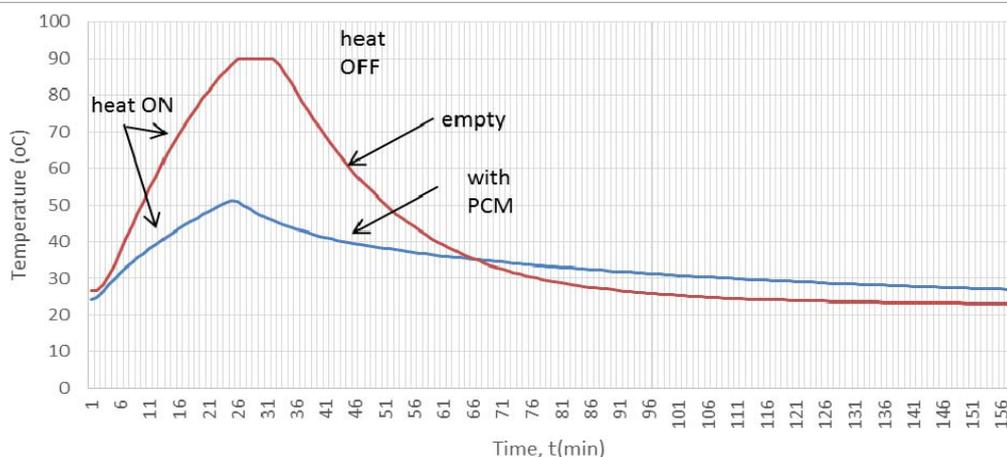


Figure 6: Heating cycle test on cabins covered with PCM and with empty walls.

with PCM and with empty walls. As the graphs indicate that the empty cabin (i.e., no PCM) was heated up to 90°C with a fast rate while the temperature of the PCM covered cabin was 50°C following a 30 min heating. The heat sources were then turned off and left for cooling down to room temperature. Once again, the empty cabin (i.e., no PCM) was cooled down to room temperature with a fast rate approximately in two hours while the temperature inside the PCM covered cabin was still 3-4°C higher and cooling was not leveled to room temperature following 4-5 hour.

The data given in Table 1 shows the heating rate and in 26 min for both cabins as 2.53°C/min for the empty cabin to reach 90°C

and 1.07°C/min for the PCM covered cabin to reach 50°C indicating considerable heat storage. Following turning the heat source off, the recovery rate back to room temperature for the cabins are 0.75°C/min and 0.16°C/min revealing a controlled heat release for the PCM covered cabin taking 170 min.

Figure 7 shows the cooling cycle test results on cabins covered with PCM and with empty walls. As the graphs indicate that the empty cabin (i.e., no PCM) was cooled down to -40°C with a very fast rate while the cooling of the PCM covered cabin took more time and leveled to minimum -35°C. The whole cycle was continued until the complete melting of the dry ice bags and the temperature inside the cabins was

	Heating rate in 26 min (°C/min)	Time to room temperature, min	Cooling rate to room temperature, °C/min
Empty cabin (i.e., no PCM)	2.53	88	0.75
PCM covered cabin	1.07	170	0.16

Table 1: The data for the heating cycle test.

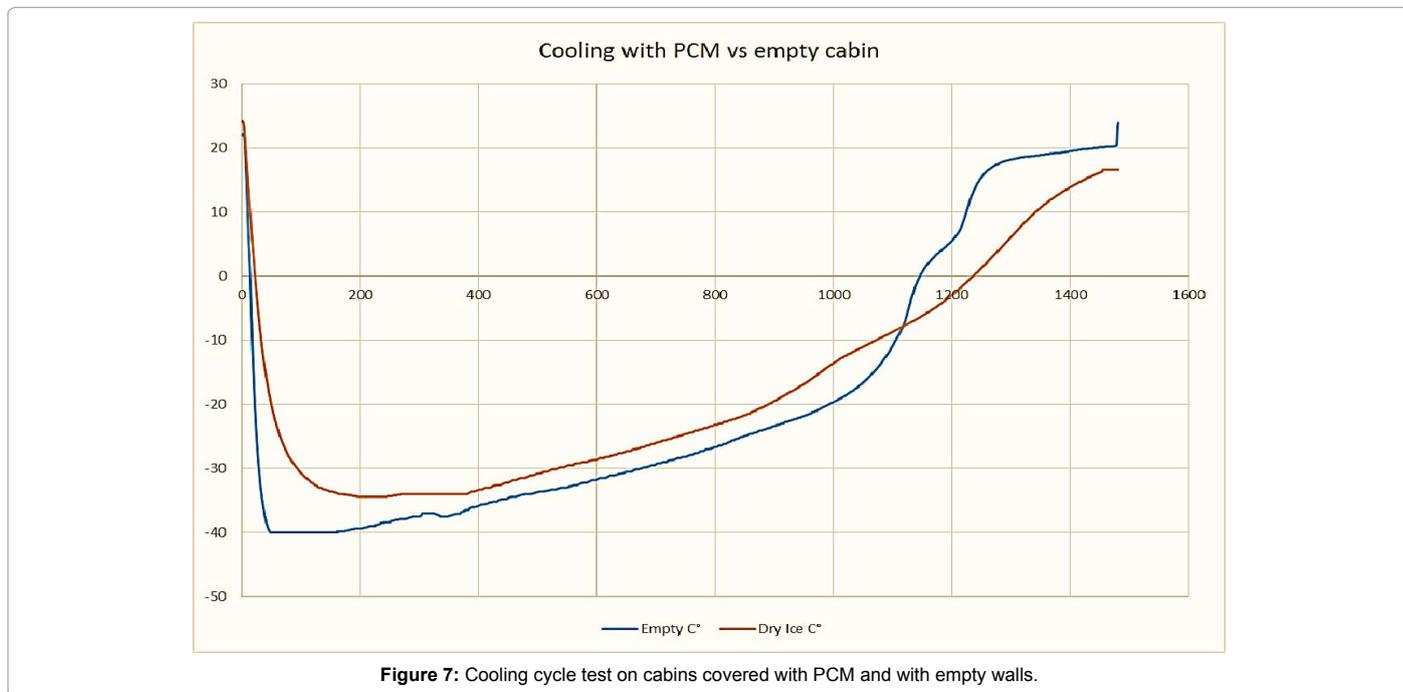


Figure 7: Cooling cycle test on cabins covered with PCM and with empty walls.

	Empty cabin (i.e., no PCM)	PCM covered cabin
Cooling rate to 0°C	2.0	1.09
Stay time <0°C, in min	1138	1218
Heating rate to room temperature, °C/min	0.18	0.06
Cooling rate to -30°C	1.80	0.60
Stay time <-30°C in min	636	435
Heating rate to back to room temperature, °C/min	0.08	0.05

Table 2: The data for the cooling cycle test.

up to normal room temperature following a 24-25 h cycle time. Once again, the temperature of the empty cabin (i.e., no PCM) was returning back to room temperature with a fast rate, while the temperature inside the PCM covered cabin was still 5-6°C lower and heating back to room temperature was not reached.

The data given in Table 2 shows the cooling rate graphs for both dry ice loaded cabins, with and without PCM. The cooling rates from room temperature down to 0°C are 2.0 and 1.09°C/min respectively indicating that considerable heat storage for the cabin with PCM covered walls. However, the time of stay below 0°C are approximately same i.e., 1138 and 1218 min respectively. The recovery rate following a complete melting of ice bags back to room temperature for the cabins are 0.18 C/min and 0.06 C/min revealing a controlled heat release for the PCM covered cabin. In similar fashion, the cooling rates from room temperature down to -30°C are taking into consideration since such low temperature levels are important especially for storage and transportation of sensitive matters such as foods, meat. The cooling rates from room temperature down to -30°C are 1.8 and 0.6°C/min respectively also indicating that considerable heat storage for the cabin

with PCM covered walls. However, the time of stay below -30°C is 636 and 435 min respectively. The recovery rate following a complete melting of ice bags back to room temperature for the cabins are 0.08 C/min and 0.05 C/min revealing a controlled heat release for the PCM covered cabin.

## Discussion

3-point bending test results given in Figures 5a and 5b for the rigid honeycomb structure made of hard Kraft paper filled with polyurethane foam indicate considerably good mechanical properties such as the maximum flexural stresses of 6.25 MPa and 13.10 MPa while the maximum flexural strain of 0.042 mm/mm. Flexural testing behavior of the honeycomb samples indicate three distinct stages. In the first stage, linear rise of the stress-extension curve within the elastic region is observed until a maximum load is reached. Following this maximum point, the second stage starts and there is a smooth drop of the curve due to the buckling of the honeycomb cell walls. The buckling and folding of the cells develops under constant stresses and eventually results in fractures of the core material. In the third stage, the stress falls due to squeezing and flattening of the cell walls. It should be noted that, following a linear behavior until a maximum point the transition of loading occurs incrementally down to a stress plateau. Such a three stage behavior of the stress-strain curve is reported for aluminum and Nomex cores [5]. It is also observed that the filling of the cores increases rigidity of the sandwich panels and enhances the resistance to the sudden impact damage.

Considering a very low weight with density values 0.70-0.80 g/cc, the rigidity, durability and flexibility of such panels make them ideal candidates for structural applications demanding such properties in transportation, space, aviation, automotive, heating-cooling systems in

buildings etc. It was also reported that the impact bending strength to density and to thickness ratios of such paper honeycomb structures is very high [7].

Open cell structure leads to a wide range of functionality for this type of structures and robust composite processing results in many different applications. Filling the open cell structure with PCM (Phase Changing Materials) along with polyurethane could bring about variety of functions such as effective insulation, heat storage and thermal management. Specially designed thermal cycle experiments reveal a highly potential heat storage functions of such panels for both high and low temperature environments. The Figures 6 and 7 demonstrate that such panels filled with PCM could efficiently absorb the heat generated inside a cabin either it is hot or cold and release it back in controlled manner. As a thermal energy storage system, three step process including charging, storing and releasing/discharging cycles are evident in these experiment [7-9]. Very slow heating and cooling rates measured during the experiments may lead into a highly managed thermal environment for any application. Applications may extent into buildings in which such panels could be used in building walls and other components to utilize natural heat such as solar energy and night cold for cooling [8]. One good application for the panels developed in this study is to incorporate them as the wallboards (floor and ceiling boards as well) for both insulation and thermal management purposes.

## Conclusion

Rigid and stiff honeycomb panels made of hard Kraft paper filled with polyurethane developed in this study result in considerably good mechanical properties. Considering a very low weight with density values 0.70-0.80 g/cc, the rigidity, durability and flexibility of such panels make them ideal candidates for structural applications demanding such properties in transportation, space, aviation, automotive, heating-cooling systems in buildings etc. Such panels also filled with PCM could efficiently absorb the heat generated inside a cabin either it is

hot or cold and release it back in controlled manner. Very slow heating and cooling rates measured during the experiments may lead into a highly managed thermal environment for any application in buildings, space, food storage, cold transportation and other structural uses. Applications may extent into buildings in which such panels could be used in building walls and other components to utilize natural heat such as solar energy and night cold for cooling. One good application for the panels developed in this study is to incorporate them as the wallboards (floor and ceiling boards as well) for both insulation and thermal management purposes.

## References

1. Reichard TW (1972) Paper Honeycomb Sandwich Panels as Lightweight Structural Components. National Bureau of Standards 43.
2. Pan J, Guo J, Ayres C (2005) Improvement of sound absorption of honeycomb panels. In *Proceedings of Acoustics*, p: 9.
3. Sendvi UKS, Napako NPZ (2007) A fatigue characterization of honeycomb sandwich panels with a defect. *Materijali in Tehnologije* 41: 157-161.
4. Stocchi A, Colabella L, Cisilino A, Álvarez V (2014) Manufacturing and testing of a sandwich panel honeycomb core reinforced with natural-fiber fabrics. *Materials & Design* 55: 394-403.
5. Barboutis I, Vassiliou V (2005). Strength properties of lightweight paper honeycomb panels for furniture. In *Proceedings of International Scientific Conference, 10th Anniversary of Engineering Design (Interior and Furniture Design)* pp: 17-18.
6. Burlayenko VN, Sadowski T (2010) Effective elastic properties of foam-filled honeycomb cores of sandwich panels. *Composite Structures* 92: 2890-2900.
7. Hasse C, Grenet M, Bontemps A, Dendievel R, Sallée H (2011) Realization, test and modeling of honeycomb wallboards containing a Phase Change Material. *Energy and Buildings* 43: 232-238.
8. Sharma A, Tyagi VV, Chen CR, Buddhi D (2009) Review on thermal energy storage with phase change materials and applications. *Renewable and Sustainable energy reviews* 13: 318-345.
9. Socaciu LG (2012) Thermal energy storage with phase change material. *Leonardo Electronic Journal of Practices and Technologies* 20: 75-98.