Numerical Evaluation of Aluminum-faced Sandwich Panels in Large Enclosure Fires

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ABSTRACT

This study investigates numerically the safety level of using Aluminum Faced Sandwich Panels (AFSP) in case of fire inside large enclosures. The investigated sandwich roof panel has three layers; inner and outer-faced aluminum sheets and an insulation core (mainly composed of rigid polyurethane foam). Different solutions like adding natural and mechanical ventilation systems are proposed to improve the safety level of the building. The Fire Dynamics Simulator (FDS) code for low-speed flows is deployed for the numerical data to be generated. FDS is an open-source software provided by the National Institute of Standards and Technology (NIST). The final results demonstrate a significant safety level improvement in the presence of the natural and mechanical ventilation systems, compared to large enclosures without the proposed ventilations.

Keywords-Aluminum Faced Sandwich Panels (AFSP); three layer roof panel; fire simulation; large enclosures; ventilation systems

I. INTRODUCTION

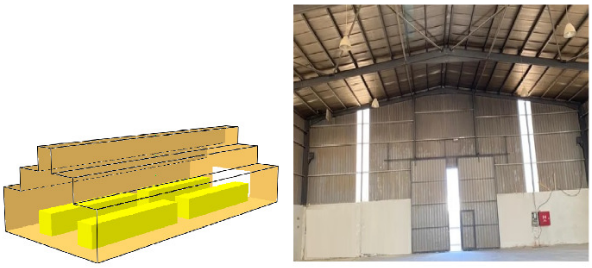
Thermal insulation materials made of a rigid foam between two metal sheets are widely used in the construction of industrial buildings and large enclosures. These light materials are very efficient in thermal insulation and can save energy. Polymer Nanocomposites have been also utilized to improve thermal insulation, fire resistance, and mechanical characterizations [1-3]. The most frequently employed types of Polymer Nanocomposites are polyurethane foams, including Polyurethane (PUR) and Polyisocyanurate (PIR) [4]. Due to its high thermal stability, PIR has the best fire resistance among all other foam materials [5]. Although this kind of material is thermally and mechanically stable and ideal for cold places, if the temperature rises beyond certain limits, sandwich panels behave differently. Thus, a safety assessment concerning fire growth inside large enclosures is very important. In such places, dealing with fire and the associated heat, smoke, and hot gases needs special treatment and more complicated procedures to be followed. Reducing the temperature inside the burning building can save the place and offer higher safety level during the evacuation process. Natural and/or mechanical ventilation produces a buoyancy effect in the burning compartment (also known as chimney effect), which helps absorb the hot gases from the interior space of the building and, thus, allow more cool air to come into the smoky area. The ventilation effect keeps the floor area at a lower level of toxic smoke and hot gases, which will offer safer exits for the firefighters and civilians being inside the building.

Several fire simulation software codes have been developed in the recent years. FDS [6] and Smart Fire [7] are well-known software implemented for special purposes, whereas CFX [8], FLUENT [9], and PHOENICS [10] are more general ones. FDS is a field model-based software developed by the NIST, USA. The FDS code solves numerically the governing equations of mass, momentum (Navier-Stroke), appropriate for low-speed energy conservation, and thermally driven flows of a multispecies gas mixture to describe the smoke and heat transport arising from fires [6]. Corner fire characteristics in a compartment have been investigated numerically and validated against the reported experimental and numerical data available in open literature [11, 12]. Numerical simulations of the fire inside different basic structures show changes in the physical properties of the hot gases, in terms of temperature, smoke visibility, and concentration of smoke particles [13]. Authors in [14] used a graphical user interface for the FDS, called Pyrosim, to perform a fire simulation in a simple enclosure. They reported and analyzed changes in temperature, smoke layer height, and heat flow under different ventilation conditions.

This study investigates numerically the safety level of a large enclosure with aluminum faced sandwich roof panels, in case of fire inside the place. The investigated sandwich roof panel, including the related physical properties and the boundary conditions, is introduced. Different solutions involving adding natural and mechanical ventilation systems are proposed to improve the safety level of the compartment during a fire breakout. The FDS code for low-speed flows has been used to generate all numerical data.

II. EXPERIMENTAL PART

The enclosure being explored includes a four production line and has 14 m width, 30 m length and 8 m height. A horizontal inlet door is located at the half of the front face. The door has a width of 6 m and a height of 3 m. The walls and floor are all made of 1/2 inch gypsum board (Figure 1). The enclosure has aluminum faced sandwich roof panels. Those consist of three layers; inner and outer faced aluminum sheets and an insulation core, mainly rigid polyurethane foam PUR/PIR (Figure 2). The latter refers to polyurethane foams involving Polyurethane (PUR) and Polyisocyanurate (PIR), respectively. PUR/PIR foam can be used long-term over a temperature range between -30^o C and +90^o C. Sandwich panel can withstand temperatures of up to 250^o C for short time periods with no harmful effects. However, exposure to higher temperature for a long time period can lead to a change in the characteristics of the foam, such as loss of shape and stability, due to thermal decomposition.



(a) (b)

Fig. 1. Invistigated enclosure: (a) Simulation, (b) Real under construction.

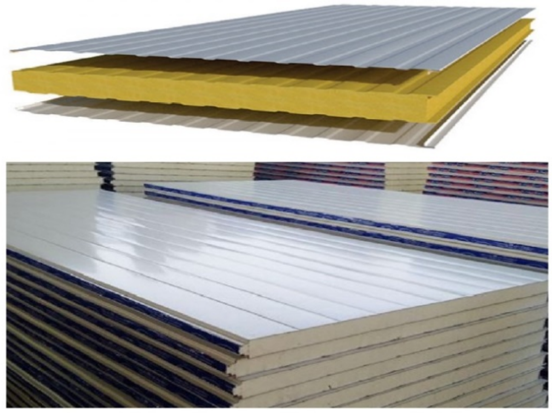


Fig. 2. Aluminum faced sandwich roof panels.

Hot gas behavior is numerically investigated for different scenarios in case of a fire breakout in the building. Only the early fire growth stage, at the first ten minutes from the beginning of the fire, is simulated and analyzed. For all the assumed scenarios the simulation time is 600 s, the fire source is the sofa or any other similar items, which give an equivalent heat release rate. Burning sofa touches the floor at 7 m far from the building's three walls and 23 m far from the main door. The location of the burning sofa is fixed at the same position for all running simulations. Figure 3 depicts the temperature profile over the fire at the early stage. Three minutes after the start of ignition, the temperature reached about 140^o C near the panels of the ceiling. At the same time, it reached about 250^o C at a height of one m above the fire.

Two scenarios are proposed to reduce the ceiling temperature. The first one is to open two side vertical vents on the top of the building, with 2 m height and 30 m width each extending along the building (Figure 4(a)). The second scenario is to add a mechanical vent (fan) with dimensions of 2 m x 2 m, which absorbs 10 m^3/s of the hot gases from the building and sends them outside (Figure 4(b)). No top open vents are available for the second scenario.

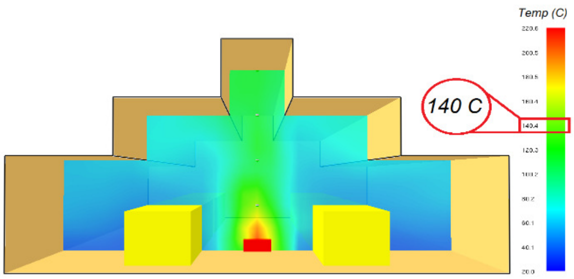


Fig. 3. Temperature profile.

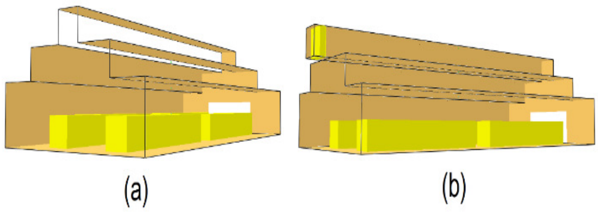


Fig. 4. Two scenarios for reducing the temperature of the ceiling.

Figure 5 displays temperature over time passing at the center of the ceiling for both scenarios compared to that without any ventilation system. Ten minutes after the beginning of the fire, the temperature of the hot gases at the center of the ceiling reaches 71° C before applying both scenarios, 24° C with natural side vents, and 60° C with a mechanical vent only. During all three cases the door is fully open.

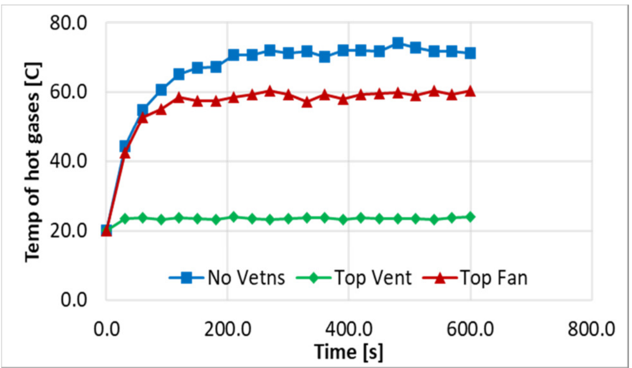


Fig. 5. Temperature over time passing.

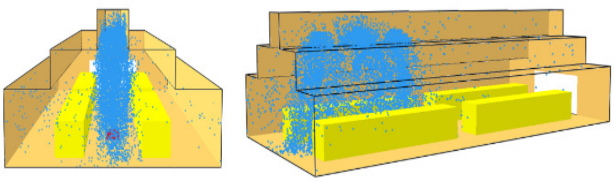


Fig. 6. Third scenario with water sprinklers.

An additional scenario is assumed, entailing switching on three water sprinklers on the top of the fire, one minute after the start of ignition (Figure 6). Figure 7 illustrates temperature over time passing for the third scenario. Ten minutes after the initiation of the fire, the temperature of the hot gases at the center of the ceiling is 41° C with spraying water.

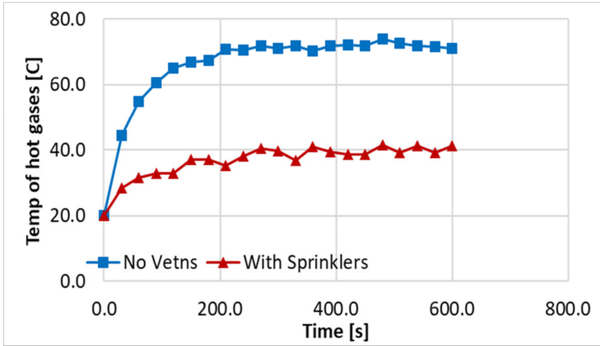


Fig. 7. Temperature over time passing, with sprinklers.

III. DISCUSSION

Long-term thermal stability of insulation materials typically exists over a wide temperature range from -30° C to +90° C. Both foams PUR/PIR can withstand temperatures up to 250° C for a short time without any deformation damage [15, 16].

The numerical results show that fire in the enclosure increases the hot gas temperature strongly up to 140° C at the ceiling level and about 250° C at a height of one meter above the fire. Without introducing cool air and cooling the place, civilians will not survive. Under such conditions, AFSP cannot also survive for a longer period of time without deformation damages [17].

The three proposed scenarios can offer more critical time and cooler environments, and this will thus improve the safety level inside the place in case of fire. If a natural ventilation system (first scenario) is provided in the place directly after the start of the fire, then the roof temperature cannot go beyond 24° C. Using a mechanical ventilation system (second scenario) can do a good job too, with the roof temperature reaching 60° C. The proposed natural ventilation system does great job, with a lower cost and an efficient performance. The natural ventilation system can outperform a firefighting system with water sprinklers, which is usually available in such places.

Another part of the problem is the accumulated smoke. Figure 8 shows the simulation results of the smoke, 1 min (Figures 8(a), 8(c), 8(e)) and 10 min (Figures 8(b), 8(d), 8(f)) after the beginning of fire. If someone compares the scenario using the ventilation system with the one using the water sprinklers, they would say that the latter does a better job as it reduces the ceiling temperature to 41° C than 60° C, but has a minor effect in reducing smoke in the place (Figure 9). This gives extra credit to the natural ventilation system again. The beauty of a natural ventilation system is that it is an environmentally friendly solution that will save more energy and will be able to provide a better lighting system in the space.

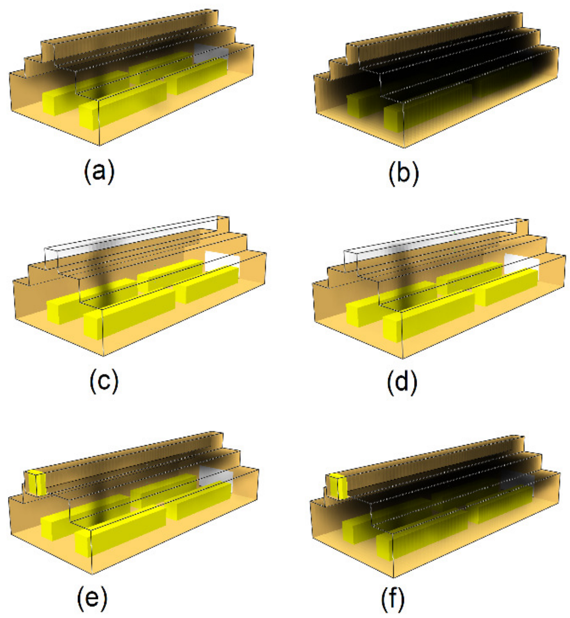


Fig. 8. Accumulated smoke: (a), (b) no vintilation, (c), (d) natural vintilation, (e), (f) mechanical ventilation.

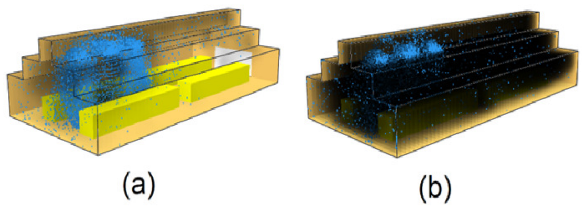


Fig. 9. Accumulated smoke with sprinklers: (a) 1 min, (b) 10 min after the beginning of the fire.

IV. CONCLUSIONS

This study investigates numerically proposed solutions to improve the safety level of a building, using Aluminum Faced Sandwich Panels (AFSP) with Polyurethane and Polyisocyanurate PUR/PIR in case of fire inside large enclosures. Different solutions like adding natural and mechanical ventilation systems are proposed. Preference was given to the unique green solutions that are in line with the current global trend.

The Fire Dynamics Simulator (FDS) code for low-speed flows is deployed in this study to generate the numerical data. FDS is an open-source software provided by NIST. The final results show a significant improvement in the safety level in the presence of the natural and mechanical ventilation systems, compared to large enclosures without the proposed ventilations

Natural ventilation can reduce the temperature, due to the buoyancy effect (for example chimney effect) in the burning region. This helps get rid of the hot gas and smoke from the place and, thus, allow more cool air to come in to the smoky area. So, it offers safer exits for the firefighters and civilians inside the building. Also the temperature to the sandwich panels stays at lower levels, thus allowing them to last for longer periods without the presence of any negative effects, like loss of shape and stability, due to thermal decomposition.

However, to give a full picture of the proposed solutions, the traditional fire sprinklers were also studied. The numerical results for the applied natural ventilation were the best among all other investigated solutions.

Natural ventilation will not only offer cheaper and cleaner solutions to improve the safety level and environment inside the building, but will also improve the lighting in the place and go hand-on-hand with the green solutions. Therefore, it will be able to reduce the energy cost of such places.

REFERENCES

[1] J. A. Al-Jarrah, D. Rbeht, M. S. E.-A. Al-Waqfi, and Y. Al-Jahmany, "Experimental Study of the Flame Retardancy of PMMA-Graphene Composite Materials," *Engineering, Technology & Applied Science Research*, vol. 14, no. 2, pp. 13324–13328, Apr. 2024, https://doi.org/10.48084/etasr.6883.

[2] M. Danikas and S. Morsalin, "A Short Review on Polymer Nanocomposites for Enameled Wires: Possibilities and Perspectives," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4079–4084, Jun. 2019, https://doi.org/10.48084/etasr.2678.

[3] A. S. Alghamdi, "Synthesis and Mechanical Characterization of High Density Polyethylene/Graphene Nanocomposites," *Engineering, Technology & Applied Science Research*, vol. 8, no. 2, pp. 2814–2817, Apr. 2018, https://doi.org/10.48084/etasr.1961.

[4] J. Kuhn, H.-P. Ebert, M. C. Arduini-Schuster, D. Büttner, and J. Fricke, "Thermal transport in polystyrene and polyurethane foam insulations," *International Journal of Heat and Mass Transfer*, vol. 35, no. 7, pp. 1795–1801, Jul. 1992, https://doi.org/10.1016/0017-9310(92)90150-Q.

[5] D. K. Chattopadhyay and D. C. Webster, "Thermal stability and flame retardancy of polyurethanes," *Progress in Polymer Science*, vol. 34, no. 10, pp. 1068–1133, Oct. 2009, https://doi.org/10.1016/j.progpolymsci.2009.06.002.

[6] K. McGrattan, B. Klein, S. Hostikka, and J. Floyd, "Fire Dynamics Simulator (Version 5) User's Guide, NIST Special Publication 1019-5," *Washington: NIST*, 2009.

[7] J. Ewer, E. R. Galea, M. K. Patel, S. Taylor, B. Knight, and M. Petridis, "Smartfire: an Intelligent Cfd Based Fire Model," *Journal of Fire Protection Engineering*, vol. 10, no. 1, pp. 13–27, Feb. 1999, https://doi.org/10.1177/104239159901000102.

[8] S. Simcox, N. S. Wilkes, and I. P. Jones, "Computer simulation of the flows of hot gases from the fire at King's Cross Underground station," *Fire Safety Journal*, vol. 18, no. 1, pp. 49–73, Jan. 1992, https://doi.org/10.1016/0379-7112(92)90047-G.

[9] D. Barrero, B. Ozell, and M. Reggio, "On CFD and graphic animation for fire simulation," presented at the 11th Annual Conference of the CFD Society of Canada, Vancouver, B.-C, Canada, 2003.

[10] D. R. Glynn, D. C. Eckford, C. W. Pope. "Smoke Concentrations and Air Temperatures Generated by a Fire on a Train in a Tunnel," *PHOENICS Journal of Computational Fluid Dynamics and Its Applications*, vol. 9, no. 1, pp. 157-168, 1996.

[11] P. K. Sharma, A. K. Ghosh, and H. S. Kushwaha, "A Computational Fluid Dynamics Study of Buoyant Plume and its Rise Time," presented at the 32nd National Conference on Fluid Mechhanics and Fluid Power, Osmanabad, Maharashtra, India, 2005.

[12] P. Sharma, B. Gera, and R. Singh, "A CFD Validation of Fire Dynamics Simulator for Corner Fire," *CFD Letters An International Journal*, vol. 2, no. 4, pp. 137–148, Dec. 2010.

[13] J. Yang, X. Pan, Z. Wang, M. Hua, and J. Jiang, "Numerical Study on the Smoke Flow Characterization and Phenomenon of Plug-Holing under Lateral Smoke Exhaust in Tunnel Fire," *Journal of Applied Fluid Mechanics*, vol. 11, no. 1, pp. 115–126, Jan. 2018, https://doi.org/10.29252/jafm.11.01.28194.

[14] H. Zhang, G. Yan, M. Li, and J. Han, "Analysis of the indoor fire risk based on the Pyrosim simulation," *IOP Conference Series: Earth and Environmental Science*, vol. 636, no. 1, Jan. 2021, Art. No. 012002, https://doi.org/10.1088/1755-1315/636/1/012002.

[15] W. Karalus, J. Dabrowski, M. Auguścik-Królikowska, and J. Ryszkowska, "Tribological properties of biodegradable polyurethanes of various structure and content of rigid elements," *Polimery*, vol. 61, pp. 509–518, Jul. 2016, https://doi.org/10.14314/polimery.2016.509.

[16] J. Datta and M. Rohn, "Thermalproperties of polyurethanes synthesized using waste polyurethane foam glycolysates," *Journal of Thermal Analysis and Calorimetry*, vol. 88, no. 2, pp. 437–440, May 2007, https://doi.org/10.1007/s10973-006-8041-0.

[17] J. Liszkowska, B. Czupryński, and J. Paciorek-Sadowska, "Temperature stability and thermal properties of polyurethane-polyisocyanurate foams obtained using products of citric acid condensation," *Polimery*, vol. 63, no. 7–8, pp. 503–514, 2018, https://doi.org/10.14314/polimery.2018.7.4.