Comparison of Thermal Insulation Performance of Different Materials Used for Aircrafts

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Abstract. For thermal insulating vehicles usually, lightweight materials are used, such as polymeric foams or microfiber insulations. But, the use of novel so-called super insulation materials can also be a good solution for this. Vacuum insulation panels can be reliable insulators for electric vehicles, too. In the paper, we will give a comprehensive review of possible applications of aerogels, polymeric foams, and microfiber insulations. Moreover, a brief introduction will be given about their thermal properties, especially focused on thermal conductivity and compressibility. Finding appropriate solutions for the aircraft industry is very important. There are several requirements for materials used by aircraft to fulfil the tightening demands, such as low weight, good noise and thermal insulation.

Keywords: Thermal insulation · Materials · Thermal conductivity

1 Introduction

In the European Union, almost 40% of all energy consumption comes from buildings, while another 20–40% comes from vehicles [1, 2]. In these cases, energy losses in mentioned sectors must be reduced. Thermal insulation of vehicles is a key point from thermal comfort, noise reduction and energetic perspective points of view. Aircraft must fly at too high an altitude to furnish, in terms of fuel economy, the best performances. Aircraft are flying at high altitudes, which can be favourable from a fuel consumption point of view but parallel to it the extreme air thermal properties should be isolated from the passengers. The air handling system is an important and essential part of aircraft because it is responsible for comfortable air distribution. The good operation of the air distributor unit of aircraft is an important task because the occupant density (passenger/m^2) is much greater in an aircraft than in a building. Moreover, the layout and the geometry are also much different [3]. It is very important for passengers to be satisfied with the noises. Noise generated by the flight and engines should be reduced as much as possible. Insulation materials are also commonly used in aircraft avionics and electrical compartment bay to protect avionics and electrical systems, which generate a lot of heat during operation. It is also used in electromagnetic interference reduction, suppression

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of surface waves and absorption of microwaves, and temperature up to 600 °C of the aircraft radar system.

As a result of technological developments, the manufacturing technique of the insulation slabs is also progressed. In the last two decades, the most used thermal insulation was the plastic foams and micro/nano fiberglass wool insulations due to their low cost and effective thermal insulation capability. But in the preview 10 years, new materials have been put on the market, such the silica aerogel or vacuum insulation panels or thermal insulation paints. These materials are usually called to nano-technological or advanced insulation materials. The goal is to achieve the required thermal level with the thinnest layer thickness as much as it is possible.

Today, the term "super insulation material" is often used for these materials. These products have much better thermal insulation properties and thus can be used in much smaller volumes and by vehicles, too. Current energy conservation standards often require space-saving insulation techniques, especially for aircraft. As the definition, therefore, new super insulation materials (SIM), such as vacuum insulation board (VIP) types, gas-filled panels (GFP) and aerogel based (ABP) products, are rapidly spreading in the insulation market. They have become an attractive alternative that reduces insulation thickness by five times [4–10]. These materials should be used between −50 °C and +70 °C, since they must stand the rapid change of temperature and the strong freeze-thaw cycles, too. For aircraft, another most important requirement to be kept is the weight. The used materials should be lightweight, but this also implies that they are compressible, and with this, it loses their thermal resistivity. Moreover, these materials should be fire-resistant, too [11, 12]. It is reported by Zhanga et al. that materials should not absorb moisture from the environment because the humidity in solid form can cause undesirable changes in the structure [13]. As it is well known, these materials should stand in extreme circumstances at an altitude of 11,000, where the pressure is about one-fifth of that of the sea level and the dampness is around zero [14, 15]. Figure 1 presents the cross-section of the cabin of an aircraft, where the insulation is highlighted by pink colour. While Fig. 2 represents an own photo of the cabin without linings and inner shell. In both figures, the thermal insulation of the cabin is shown.

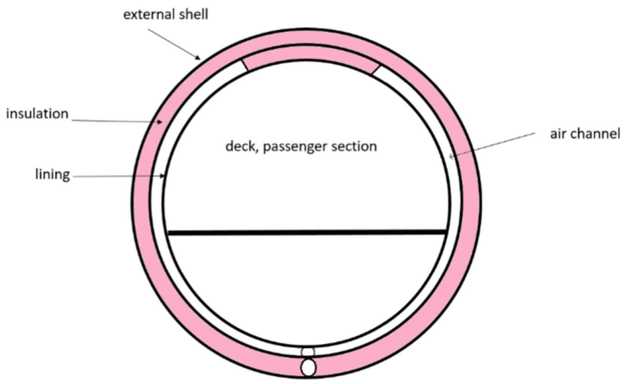

Fig. 1. Sketch of an aircraft cross-section

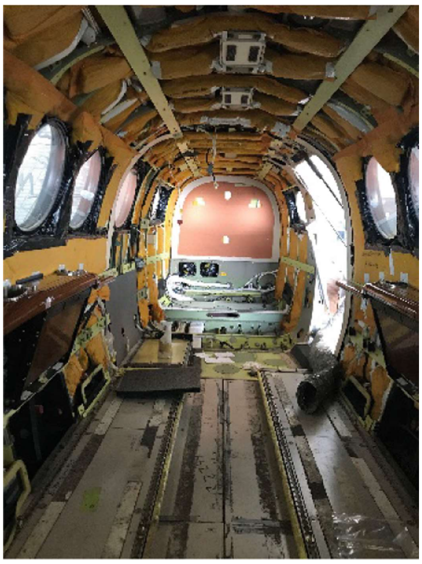

Fig. 2. The fixing of the insulation

The main purpose of the paper is to give a comparison of the thermal properties of insulation materials used for aircraft. Thermal tests executed on three different types of insulations are presented in the paper.

2 Materials and Methods

Thermal insulation materials are responsible for separating spaces having different temperatures. Further tasks and requirements for them, besides the thermal insulation and the reduction of energy use, is the fire prevention, good mechanical load-bearing capacity, and protection of materials and equipment nearby against chemical and mechanical damage, too.

2.1 The Tested Materials

Microfiber Insulations.
Microfiber blankets are weightless, bouncy, thermal and audial insulating materials designed as insulting air spaces to prevent body heat dissipation. These are equipped with a water repellent thermoplastic phenoplast coating which is flame-retardant and provides outstanding planar balance. An additive is used to supply water repellency to the healed blanket for repair in areas where towering altitude moisture condensation may occur. In a situation where moisture is not a concern, the clear phenoplast layer can be characterized. These blankets tender excellent audial and thermal pursuance per unit weight of insulation used. Blankets are phenoplast shackled, fireproof, and easily meet the overall heat release standards. Since the blankets are sub-cellular and moisture-resistant, they

will not assist life growth. They also provide excellent balance with age. The extraordinary flexibility of the optical fiber prevents single-particle arbitrating and holds their outstanding sound debilitation and thermal effects [10]. Two types of insulations have been tested, an orange and a pink one (see Fig. 3. and Fig. 4.).

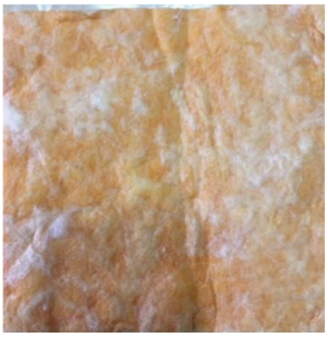

Fig. 3. The tested microfiber insulate #1

Fig. 4. The tested microfiber insulate #2

Polymeric Foam.

Polymeric aircraft foam products can be good insulation material to meet the strict requirements of the aerospace and airplane industries. They provide outstanding audial and thermal insulation at a greatly low weight and keep planar stability and alterability over a full temperature range. With an evidenced in-service long-lasting record in humid, hot surroundings, they outmatch conventional fiberglass insulation by holding insulating features far longer. Polymeric foams are independent and non-stringy making them simple to handle, fast to install and requiring fewer fasteners. They can be found in falcon, Airbus, Boeing, hawker, Embraer, business jets, military aircraft and helicopters, equally in particular aerospace applications, along with the worldwide Space Station, Mars Rover, solar-energy shields and cryostat fuel tanks. The tested material has a density of about 15 kg/m^3, see Fig. 5 [16].

Fig. 5. The polymeric foam

Slentex Aerogel.
Sensex is a blanket based on silica aerogel that is non-combustible, thus meeting the increased fire protection requirements and can be directly moulded, i.e. easily fitted to surfaces that we would not normally be able to reach. Due to this, it is also suitable for hard-to-reach surfaces where an elevated level of fire is mandatory. It is often used to insulate ventilated facades as it is a thin quilt so we can save valuable space for the benefit of the ventilation system. It can also be used as insulation for vehicles. Slentex thermal insulation is also known as Spaceloft A2 (see Fig. 6.).

Fig. 6. The tested slentex insulation

2.2 Thermal Conduction

Thermal conduction is a form of heat dissipation in which particles of matter do not move out of their macroscopic equilibrium. Heat is propagated from molecule to molecule by the collision of different medium velocity molecules and by the diffusion of free electrons in metals, as a result of the thermal energy, the vibration energy of the particles increases. Materials conduct heat to varying degrees. To characterize the degree of conductivity, we use the thermal conductivity (λ *in W/mK*), which is a material constant. One of the most important thermophysical properties of thermal insulation materials is thermal conductivity. The thermal conductivity of homogeneous solids can be easily determined by measuring the equilibrium heat flux (j_q *in W/m*^{2}) that flows in the sample under the influence of a temperature gradient (*grad T*); this is written by Eq. (1) and also presented in the latest paper [10]:

$$j_q = -\lambda \times (grad(T)) \tag{1}$$

2.3 Test Procedure

In our laboratory, the thermal conductivity of the materials is measured with a Netzsch HFM 446, presented in Fig. 7; with this apparatus, less than 3% accuracy can be reached. This machine can be used to test thermal insulation materials. The device operates as described in ISO 8301 [17]. Materials with geometries 20 × 20 × 1–5 cm thick can be tested in the measuring chamber. The measurements were performed in each case after drying them to constant weight in a Venticell (111) desiccator. Drying of the tested samples did not yield measurable moisture content due to the 24 h drying.

Fig. 7. The Netzsch 446 HFM

The device is also suitable for measuring the specific heat capacity (c_p, J/kgK) of materials, and its thermal conductivity can be examined under different loads and compressive forces. Moreover, the equipment can measure the change in the thickness of the samples within the calliper after applying different compressing loads from 0,5 to 15 kPa (Fig. 8).

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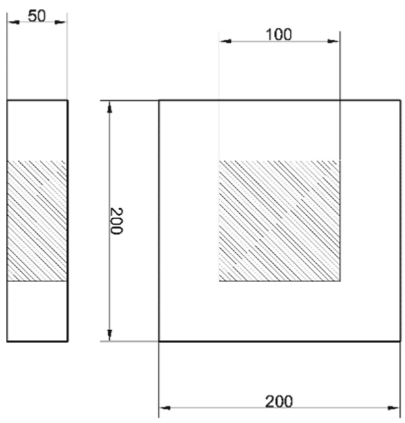

Fig. 8. The test section of the equipment

In this heat flow meter, the 20 cm × 20 cm sample is placed between two heated plates, as in the case of the equipment mentioned above. The heat flow (J_q in W) through the sample is generated by a temperature difference ΔT (in °C or °K). Moreover, the heat flow further depends on both the thermal conductivity and the thickness of the material (*d, cm*), see Eqs. (1) and (2), where *A (in* m^2*)* is the surface area of the sample. The measurement details are written in the latest paper by the Authors [10].

$$J_q = \lambda \times A \times \Delta T/d \quad (2)$$

3 Results

Thermal conductivities of four insulation materials, polymeric foam, two microfiber insulation and an aerogel, were measured with Netzsch 446 HFM equipment. The mean temperatures during the measurement were fixed to 0, 10, 20 and 30 °C, and the temperature difference between the plates was fixed to 20 °C in each case. In Table 1, we have represented the initial data of the samples, such as the density and thickness.

Table 1. The properties of the tested materials

Tested materials	Density [kg/m^3]	Thickness [cm]
Slentex - aerogel	191.1	1.05
Pink - microfiber	13.64	3.02
Orange - microfiber	29.58	4.02
Plastic foam	17.6	1.2

Figure 9 presents the measured thermal conductivities of the samples. It is noticeable that the thermal conductivities are increasing with the increasing mean temperatures. The values of the polymeric foam and the pink microfiber increase by about 16% if the temperature difference rises from 0 to 30 °C. The values of the orange microfiber raise under the same temperature change by about 14%, however, the values of the slentex aerogel rise only by 5%, and it also has the smallest measured thermal conductivity. It is further noticeable that the density of the slentex aerogel is much greater than the others,

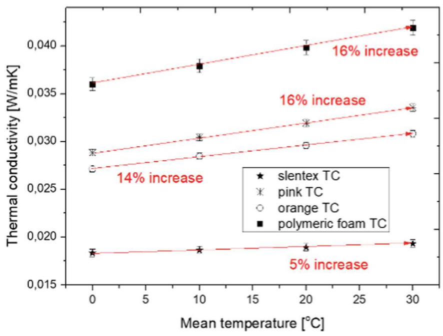

Fig. 9. Comparison of the measured thermal conductivities

which gives an applicability limit to this material. To the weight problems of aircraft, this material cannot be used in all places of the aircraft.

To better understand the thermal conductivity results and to suggest a possible application, we have calculated the thermal resistances (*R*, $m^2 K/W$) of the samples at different temperatures from the tested materials by following Eq. (3):

$$R = d/\lambda \tag{3}$$

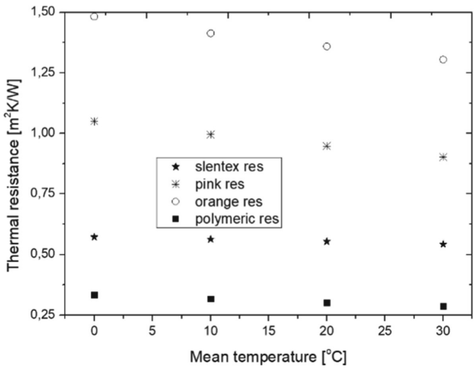

Fig. 10. The calculated thermal resistances

The calculated thermal resistances in the function of the temperature are shown in Fig. 10. One can see the highest thermal resistance belonging to the orange and the pink, while the polymeric foam and the slentex have less. It should also be mentioned that the orange and pink microfibers are very compressible (lightweight), so they cannot be used where load-bearing insulations are needed; we suggest their use by the deck, while in those cases where the materials should stand the weight, slentex with its increased density and low thermal conductivity is suggested to use.

Compressibility Experiments

With the Netzsch HFM, we have tested the compressibility of the samples through the registration of the thicknesses after applying different loads from 1 to 15 kPa. The results are presented in Fig. 11. From this figure, one can see that the relative change in the thickness of the samples increases with the increasing loads, but the changes are the greatest for the two micro-fiber insulations (pink and orange) followed by the plastic foam, and the change is less for the slentex aerogel.

Mass to Area Ratio

To see the effect of the density of the samples, we have calculated the specific mass of the materials in kg/m^2 units. If one multiplies the density with the thickness of the materials, one can reach a specific mass value. From this by using the data in Table 1, we have reached the results presented in Table 2. However, we have mentioned above that the lowest thermal conductivity belongs to the aerogel as well as it also takes the mass to area ratio of 2 kg/m^2.

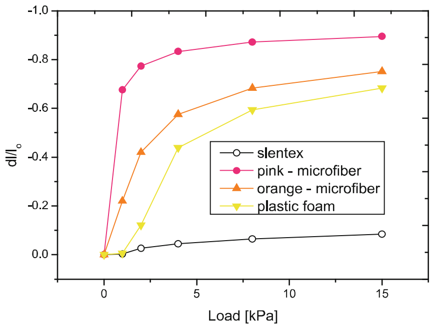

Fig. 11. The compressibility test results

Table 2. The mass/area ratio

Tested materials	Mass/area [kg/m^2]
Slentex - aerogel	2
Pink - microfiber	0.4
Orange - microfiber	1.2
Plastic foam	0.21

Evaluation of the Results

To compare the most important properties of the thermal insulation used for aircraft we have collected the resistances, compressibility and the mass to area ratios in a table (see Table 3.) We have evaluated the samples from 1 to 4 where 1 means the best, and 4 means the worst value from a usability point of view.

Table 3. Evaluation of the samples

The property	Slentex	Pink - microfiber	Orange - microfiber	Plastic foam
Resistance 0 °C	3	2	1	4
Resistance 10 °C	3	2	1	4
Resistance 20 °C	3	2	1	4
Resistance 30 °C	3	2	1	4
Compressibility	1	4	3	2
m/A ratio	4	2	3	4
Sum value	17	14	10	22
Final result	III	II	I	IV

As is visible from Table 3, the overall rate for the samples resulted in the benefit of orange microfiber insulation, followed by the pink microfiber, the aerogel and the plastic foam, respectively. We consider the insulation most appropriate if it has a less sum value.

4 Conclusions

Aircrafts must fly at too high an altitude to furnish, in terms of fuel economy, the best performances. Thermal insulation materials used for aircraft must fulfil several requirements such as a) reducing heat loss, b) should be non-flammable, should reduce noise and must be lightweight. Advances in airplane thermal insulation supply better passenger safety, less fuel use, greater plane availability, better noise reduction as well as faster and easier operation, maintenance, and installation.

In this paper, we have presented results of thermal conductivity and measurements executed on the most important insulations used by aircraft. We have compared the thermal conductivities and the thermal resistances of the samples. Firstly, we have revealed that the thermal conductivity change of the samples by the temperature is the least for the slentex aerogel, having the smallest thermal conductivity. After calculating the thermal resistance of the samples, we have reached that the orange and pink microfibers have the highest resistance value. Secondly, we have shown that the greatest change in the thickness of the samples by compression loads belongs to the pink and orange microfibers, followed by the plastic foam and the slentex aerogel. We have stated that in places where the load-bearing is not necessary, the conventional colourized microfibers can be used, taking into account the sensitivity of the thermal conductivities from temperature, while in places where the weight should be considered, such as luggage compartments, the use of slentex insulation, is recommended. It was started with compressibility measurements, too. Moreover, we have executed an overall rating procedure where we have taken into account the resistances at different temperatures and the mass to area ratio.

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