Thermal Properties and Microstructural Assessment of Glass Composites with Epoxy Matrix for Cryogenic Applications

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ABSTRACT

Thermal properties of materials, especially their thermal conductivity and emissivity, are extremely important in the efficient design of terrestrial cryogenic equipment, such as Dewars and cryostats. It is widely known that composite materials based on epoxy resin and glass reinforcement are good candidates for applications in extreme temperature conditions due to their high stiffness together with low thermal conductivity. However, previous works have been limited only to thermal conductivity and narrow temperature range. Our study investigates the effect of several resin matrixes on thermal conductivity (from 5 K to 300 K) and on total hemispherical emissivity (15 K÷300 K).

1. INTRODUCTION

Thermal conductivity (λ) is crucial in designing devices for extreme temperatures. Most studies in polymer thermal analysis aim to enhance thermal conductivity rather than improve insulation. However, applications like pipe insulation, building insulation, thermos flasks, and food containers require effective thermal insulation. Several factors are considered also in designing a cryostat, such as operating temperatures, heat load limits, size and weight constraints, and expected lifespan [1]. In composites, thermal conductivity is anisotropic, requiring precise knowledge for accurate design and it depends on fiber and resin conductivity, sample geometry, and fiber packing [2].

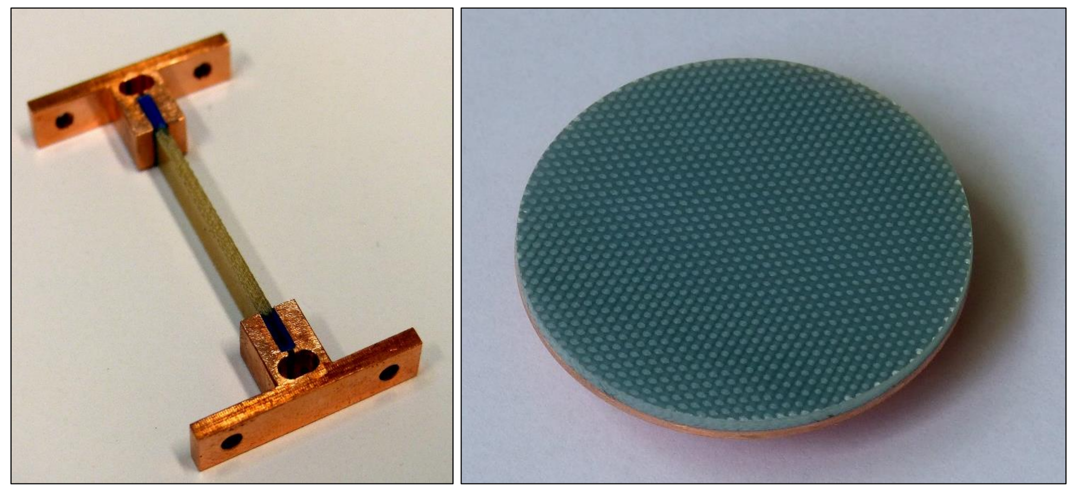

Fig. 1. *Example of samples prepared for testing of thermal conductivity λ (left) and emissivity ε (right).*

Thermal radiation presents another important mode of heat transfer in cryogenic systems. The amount of radiative heat exchanged between bodies is proportional to the difference between the fourth power of their absolute temperatures [3]. In addition, it also depends on emissivity (ε) of the surface, i.e. on the ratio of the total emitted radiance to that one of a perfect black body radiator at the same temperature.

This investigation aims to determine the thermal conductivity and emissivity of epoxy-glass composites with different hardeners from cryogenic to room temperature.

Two epoxy-glass laminates produced by IZO-ERG company (Gliwice, Poland) were used in this study. The laminates were made using:

Epoxy resin: **YDPN 638A80** (Kukdo, South Korea)
Hardeners: **Novolac P** - laminate **EP_1_1**
DDS - laminate **EP_1_3**

2. MEASUREMENT CHARACTERIZATION

Apparatus for λ as well as ε measurements at low temperatures has been designed and developed at Institute of Scientific Instruments Brno. They use liquid helium bath for cooling.

EMISSIVITY MEASUREMENT: the method is based on measurement of radiative heat power Q_R exchanged in vacuum between two parallel 40 mm concentric discs, the radiator (examined sample at temperature T_R, Fig. 1, right) and the absorber (at T_A) . The emissivity of the sample is evaluated as $\varepsilon(T_R)=Q_R/A\sigma(T_R^4-T_A^4)$, where A is the sample area, σ Stefan–Boltzmann constant. Further details about the method and the apparatus (Fig. 2, top) can be found in our previous work [5].

CONDUCTIVITY MEASUREMENT: have been conducted using a modified apparatus presented earlier (for details see [5]). It measures the integral thermal conductivity $\kappa(T_A, T_R)$, while the specific thermal conductivity λ(T) is evaluated by derivation of κ at selected setpoints. T_R and T_A presents the measured temperatures on the hot and cold end of the sample. Samples dimensions are about 5 mm x 35 mm (Fig. 1, left).

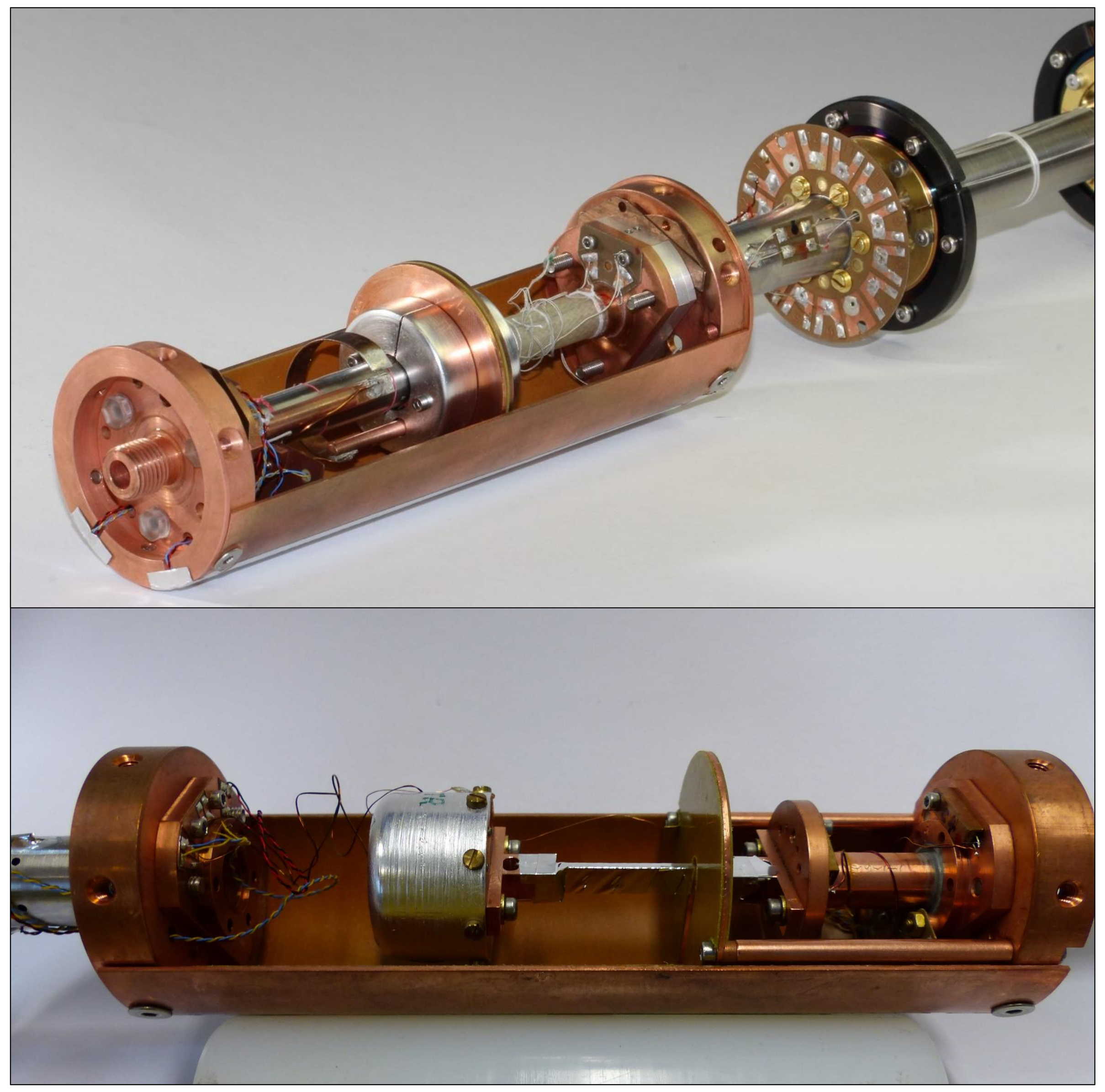

Fig. 2. *Opened chamber of the apparatus for measurement of ε (top) and λ (bottom).*

3. EXPERIMENTAL RESULTS

Thermal conductivity of both samples reached low, but different values typical for insulators and increased with temperature (Fig. 3). As can be seen in Fig. 4, their emissivities increased up to 90% and were similar to our „black" reference [4].

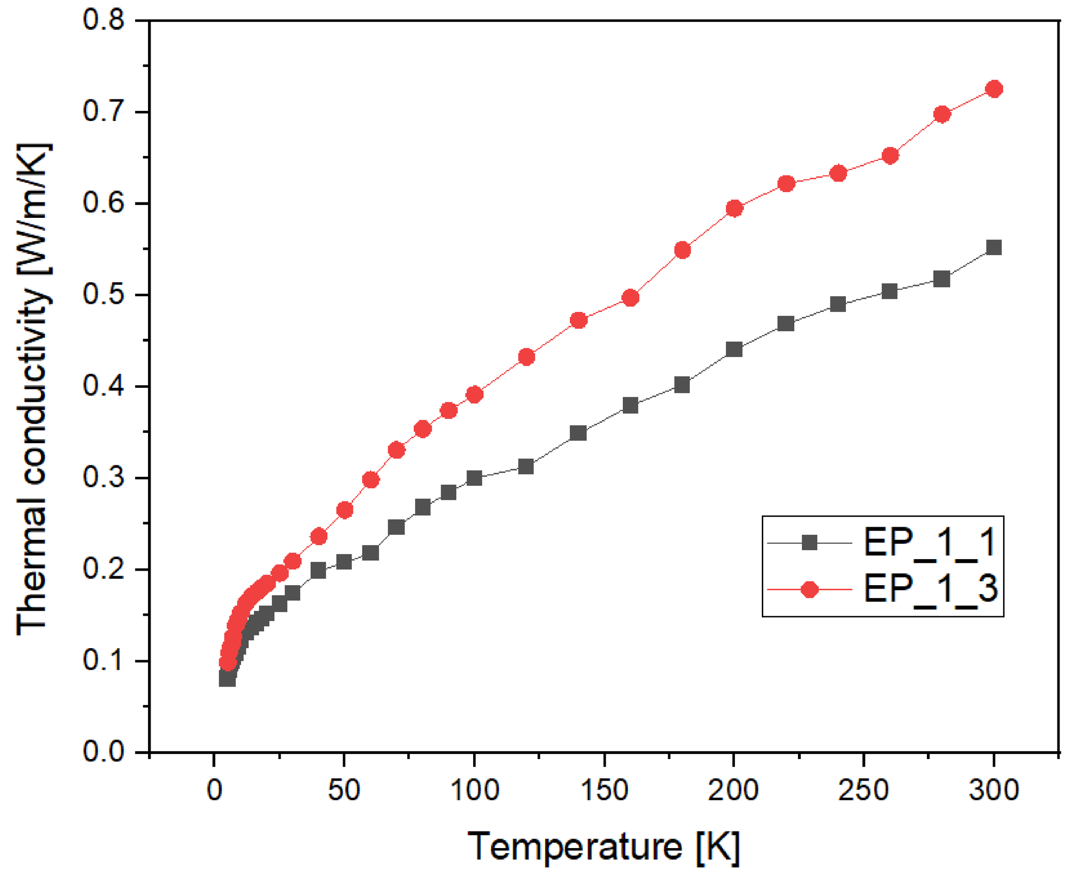

Fig. 3. *Thermal conductivity of epoxy-glass laminates in the range of 5 K to 300 K.*

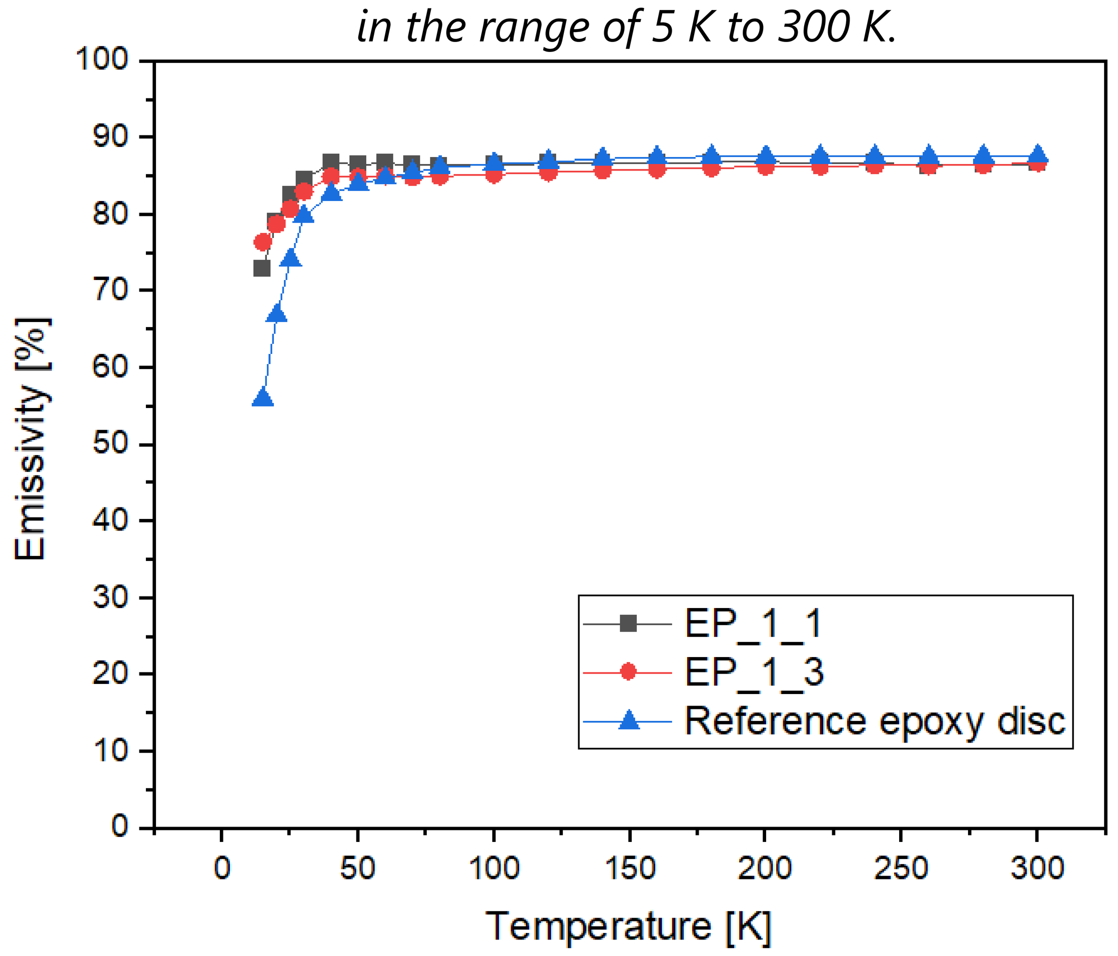

Fig. 4. *Emissivity of epoxy-glass laminates in the range of 4.5K to 300K.*

4. CONCLUSIONS

The choice of the hardener affected the thermal conductivity (λ). Samples with DDS had the highest λ values from 5 to 300 K. Future research will consider fillers that reduce λ. On the other hand, emissivities were similar except the lowest temperatures. Extended research is ongoing on other composite materials, with plans to conduct ANSYS simulations to study their behavior under different conditions, particularly as insulators in cryogenic tanks or Dewar vessels

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