THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

GRADUATE SCHOOL
研究生院

Undergraduate Research and Innovation Scheme (URIS)

Progress Report

√ Completion Report

(Please tick "√" as appropriate)

Section A: The Project and Project Team Members

1. Project Title

Development of a Hybrid De-Icing System using Aerogels for Aircraft Applications

Project Type: ☐ Individual project

√ Group project

Project ID P0043663 **Work Programme** 1-TABX

2. Project Team Members

Name	Department	Role
SHEN Xi	AAE	Chief Supervisor
		Co-Supervisor *(if any)*
LUA Adrian Shalom Sy	AAE	Student Project Leader
KIM JaeYoun	ME	Student Project Member *(if any)*
ANG Jershon Ainsleigh Entote	AAE	Student Project Member *(if any)*
FERNANDO Nivain Devnith	ME	Student Project Member *(if any)*
WEERASINGHE Kasuntha Gimshan	ME	Student Project Member *(if any)*

3. Project Duration

	Original	Revised	Approval Date of Change Request (Mandatory)
Project Start Date	1 Sep 2022		
Project Completion Date	31 Aug 2023		
Duration *(in months)*	12		

Section B: Report on Project Progress

4. Summary of Objectives Achieved

Objectives as per Proposal	Percentage Achieved (Estimated)
1. To develop a composite aerogel with high optical absorption and low thermal conductivity to achieve high efficiency of photothermal conversion.	100%
2. To optimize the electrical conductivity of the aerogel while retaining its good optica absorption, allowing heat generation from Joule heating.	100%
3. To integrate the aerogel into carbon fiber reinforced polymer (CFRP) composites to provide mechanical stability for aircraft applications.	20%
(Add more rows, if needed)	

5. Research Activities

a) Progress made during the reporting period

Throughout the project duration, multiple aerogel samples with different compositions (as seen in Table 1) were developed, each one optimized to achieve the desired material properties. The aerogels were fabricated mainly using biomass sources, providing better sustainability practices in the research. Pyrolyzed banana peels were used as the source of carbon fillers, which act as solar absorbers, for the composite aerogels, instead of traditional sources such as carbon nanotubes or graphene. The fabricated aerogel sample, as shown in Figure 1, has dark appearance, which is essential for absorbing solar energy and converting it into heat to increase the surface temperature for de-icing functions. In addition, the highly porous and anisotropic structure, as shown in Figure 2, can not only promote extensive light-scattering, further enhancing the solar absorption, but also minimize the heat transfer in the through thickness direction, allowing heat localization on the top surface which exposed to the sunlight for more-efficient de-icing performance.

Table 1. Compositions of Aerogel Samples Fabricated.

	Pyrolyzed banana peel	**Carbon nanotube (CNT)**	**Polyurethane (WPU)**
Composition 1	50 wt%	0 wt%	3.6wt%
Composition 2	50 wt%	1.36 wt%	3.6wt%
Composition 3	50 wt%	2.7 wt%	3.6 wt%

Figure 1 Digital image of aerogel sample fabricated using biomass materials by unidirectional freeze-casting.

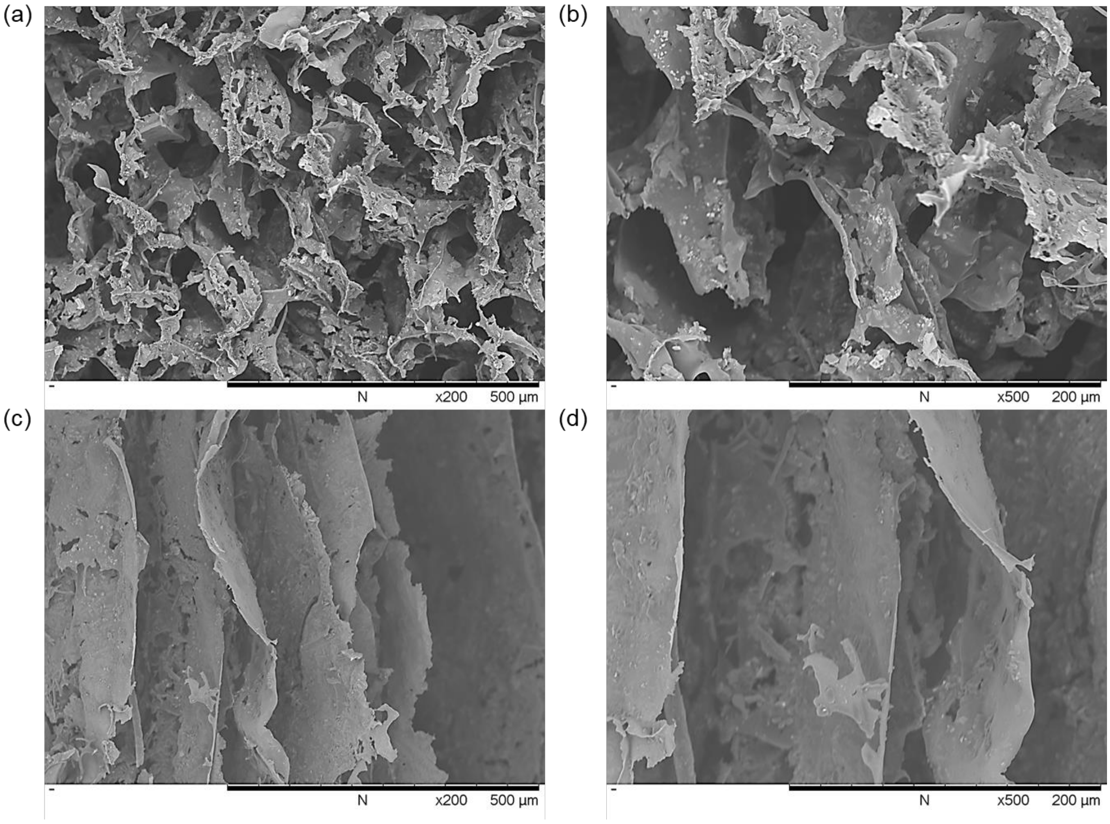

Figure 2. SEM images showing the (a,b) cross-section and (c,d) alignments of biomass-based aerogel samples under magnifications of 200X and 500X.

b.)Significant results and deliverables achieved

1. *To develop a composite aerogel with high optical absorption and low thermal conductivity to achieve high efficiency of photothermal conversion.* (100%)

Through the optimization, the composite aerogel fabricated using WPU concentration of 3.6wt% and filler loading (pyrolyzed banana peel) of 50 wt.%, with dimensions 12cm (L) x 4cm (W) x 1.5cm (H), exhibited good photothermal characteristics, reaching a top surface temperature of up to 55 °C under one sun (~1 kW/m^2). Based on photothermal tests, the team determined that the aerogel can adequately absorb sunlight with minimal heat dissipation, marking a step towards a fully functional solar de-icing surface. Additionally, from the temperature profile in Figure 3, excellent insulation performance can also be observed from the aerogel samples.

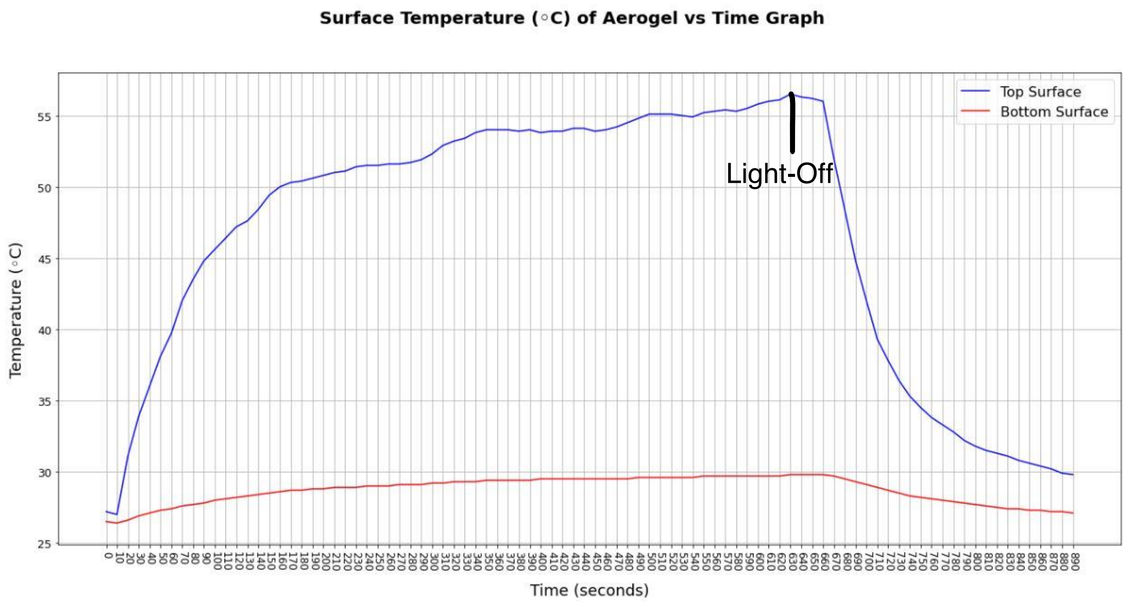

Figure 3. The change in temperatures at top surface (blue line) and bottom surface (red line) of biomass-based aerogel samples under one solar irradiation for ~10 minutes and light-off for ~5 minutes.

The remarkable thermal characteristics of the aerogel can be attributed to its porous structure, as observed in Figure 2. The porous structure allows the aerogel to absorb significant amounts of sunlight. When sunlight is absorbed, heat can be retained on the top surface due to the aerogel's thermal insulation properties. Hence, such a result can be obtained.

Additionally, after exposing the aerogel samples to solar irradiation under one sun, a de-icing test was also performed to determine the ability of the aerogel to maintain the heat absorbed. This was done by placing a 2.54cm x 2.54cm x 2.54cm ice cube on top of the sample and determining the time it takes for the cube to melt completely. The setup of this test can be observed in Figure 4. This setup was compared with a control setup where the ice cube was not rested on the aerogel sample. It was found that the ice cube placed on top of the aerogel sample took 1:16:47.53 (1 Hour, 16 Minutes, and 47 Seconds) to melt, whereas the control setup ice cube took 1:34:37.64 (1 Hour, 34 Minutes, 37 Seconds) to melt.

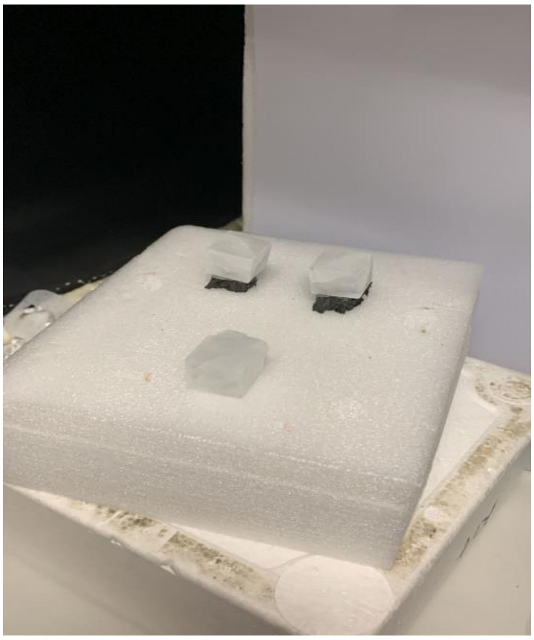

Figure 4. De-icing test.

2. *To optimize the electrical conductivity of the aerogel while retaining its good optical absorption and electrical resistivity, allowing heat generation from Joule heating.* (100%)

To allow heat generation by Joule Heating, sufficient electrical current must flow through the aerogel when voltage is applied. However, to maximize de-icing performance, the aerogel must also exhibit electrical resistivity such that sufficient heat can be generated. This relationship with heat generation is observed in Equation 1.

$$Q = I^2 \times R \times t \quad (1)$$

Where:

I – Electrical current
R – Electrical resistance
t – time

To achieve this, small amounts of one-dimensional (1D) carbon nanofillers, carbon nanotubes (CNTs), were doped into the subsequent samples to create electrically conductive pathways throughout the aerogel. Separate samples were doped with 1.36 wt.% and 2.7 wt.% CNT, respectively. It is crucial that only small amounts of CNT are added in order to maintain the efficiency of resistive heating. Using an LCR Meter to measure for electrical resistance and converting the obtained values into electrical conductivity, the electrical conductivities of the CNT-doped samples were found to be 0.00083 and 0.01 S/m for the 1.36 wt% and 2.7 wt% samples, respectively.

It was observed that, the maximum surface temperatures of the samples doping with CNT decreased, as shown in Figure 5a (2.7 wt.%) and Figure 5b (1.36 wt.%). This is possibly due to aggregation of CNT with the aerogel matrix which reduces the optical transparency of the aerogel. Other possibilities for this observed phenomenon include structural inhomogeneity and optical matching. However, it can also be observed that, for the CNT doped samples, the average temperature does not drop within the timeframe of the experiment. This suggests that, despite achieving a lower maximum surface temperature, the CNT doped samples, compared to their non-doped counterparts, exhibit better thermal insulation and longer heat storage times.

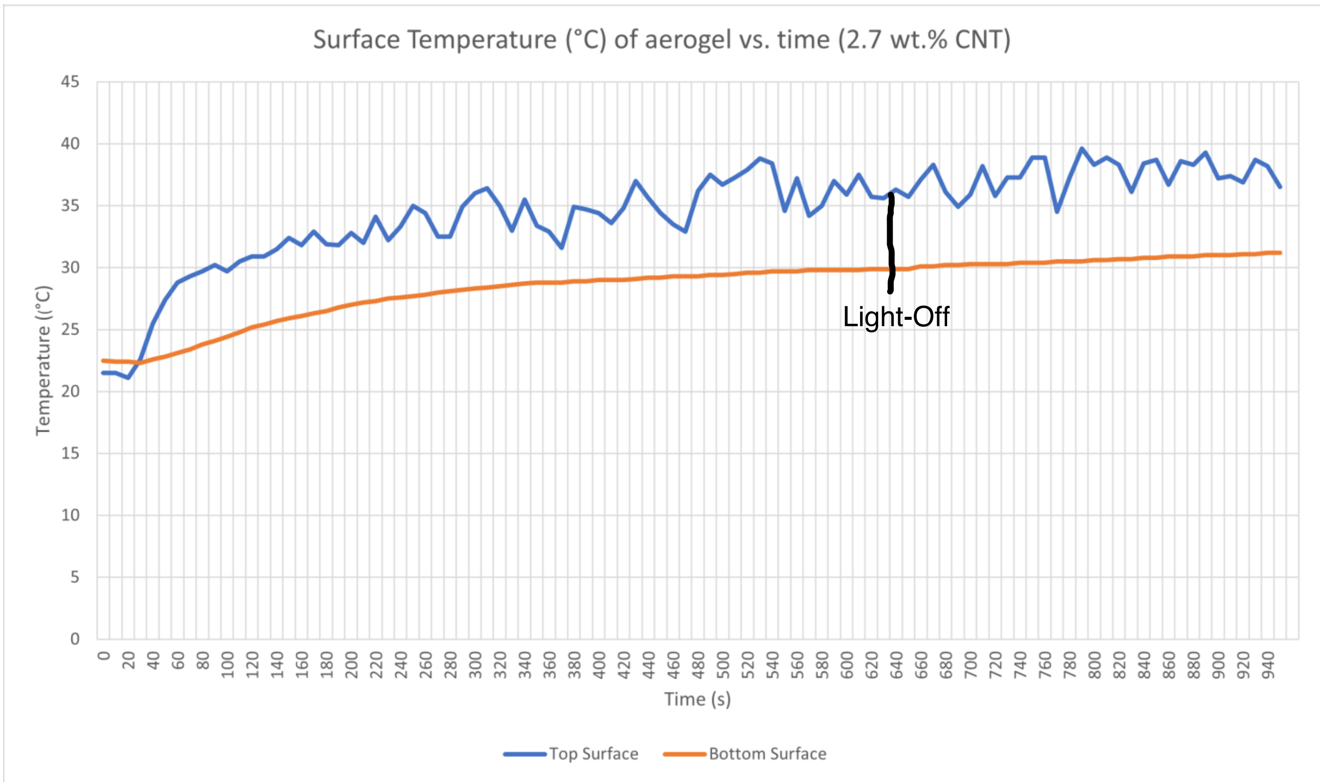

Figure 5. The change in temperatures at top surface (blue line) and bottom surface (red line) of CNT-doped (2.7 wt%) biomass-based aerogel samples under one solar irradiation for ~10 minutes and light-off for ~5 minutes.

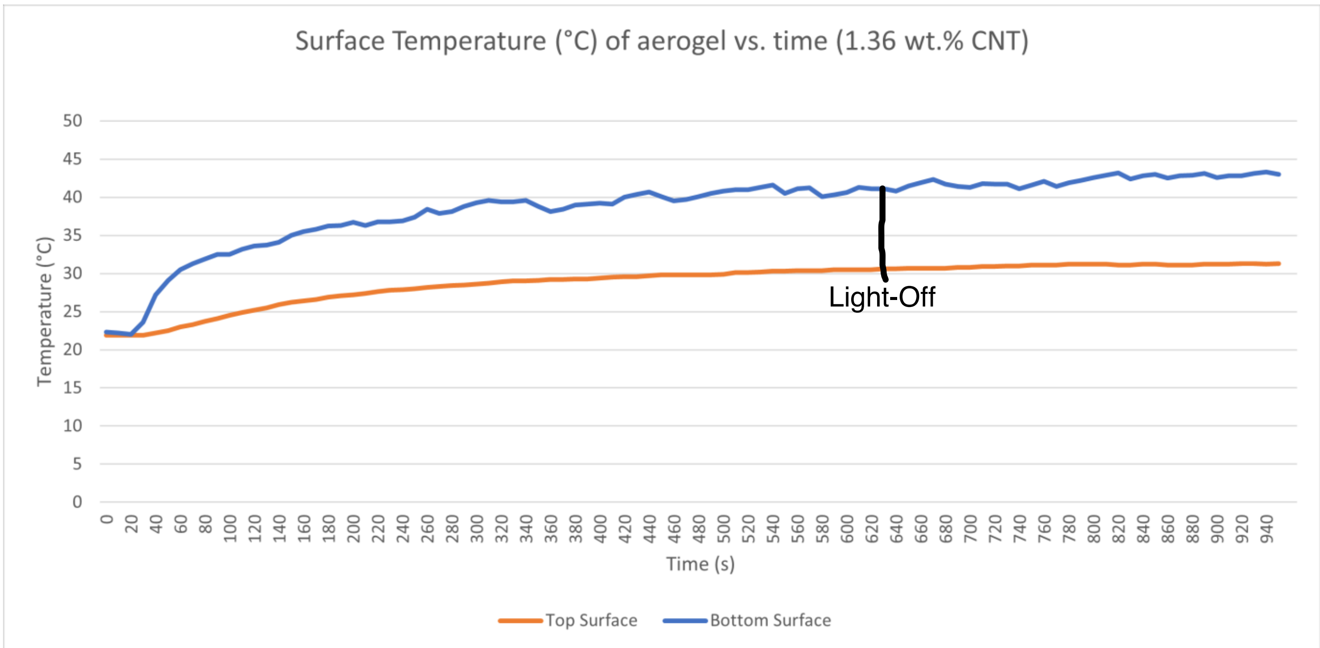

Figure 6. The change in temperatures at top surface (blue line) and bottom surface (red line) of CNT-doped (1.36 wt. %) biomass-based aerogel samples under one solar irradiation for ~10 minutes and light-off for ~5 minutes.

3. *To integrate the aerogel into carbon fiber reinforced polymer (CFRP) composites to provide mechanical stability for aircraft applications.* (20%)
   Because of the lengthy optimization process of the aerogel which involves repeated experimentation, fabrication, and testing of samples, the aerogels had not been integrated into carbon fibre reinforced polymer composites. Furthermore, several equipment breakdowns had also severely delayed the progress, making the integration unfeasible within the given time frame. However, several literature reviews had been conducted, and it was determined that several integration methods, such as epoxy resin infusion and prepreg composite layup with the aerogel part of the reinforcement, are feasible processes which can be explored in future studies.