fluids

Supplementary Materials: Recycled Cellulose Aerogels from Paper Waste for a Heat Insulation Design of Canteen Bottle

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S1. Design of Sandwich Structures

For the internal layer, nylon in Figure S1(a) was chosen over the others due it having the lowest thermal conductivity value, high durability, low cost, high availability and smooth texture. The heavy-duty fabric of neoprene in Figure S1(c) was chosen as the external layer of the thermal jacket due to it having low thermal conductivity, excellent durability, mostly weather-proof properties, high abrasion properties and tear resistance. Figure S1(d) shows the proposed sandwich layer using different materials forming the insulated jacket.

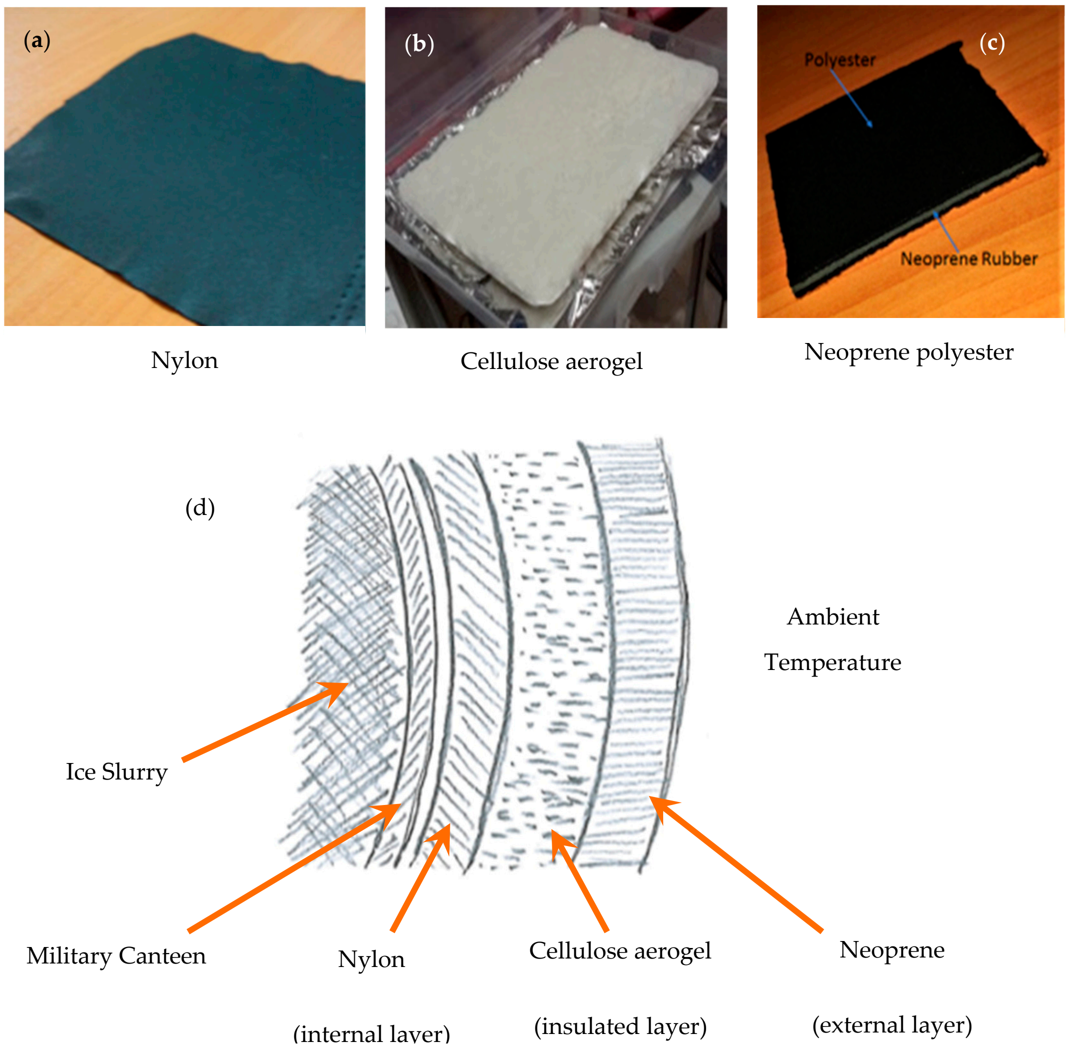
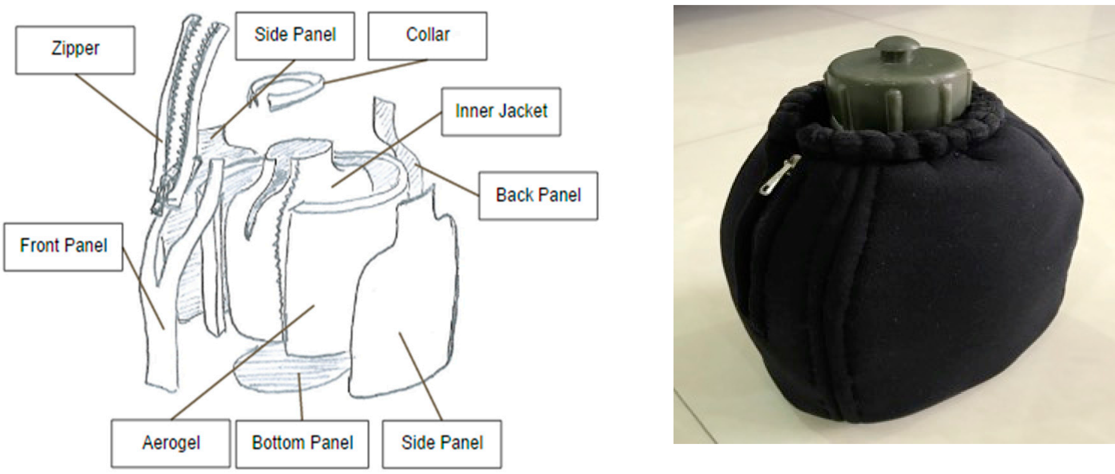


Figure 1. Materials of (**a**) nylon, (**b**) cellulose aerogel, (**c**) neoprene used for the insulated jacket design, and (**d**) the sandwich structure consisting of neoprene as the outmost layer, the cellulose aerogel within and nylon as the innermost layer.

S2. Prototype Fabrication Process of the Thermal Jacket

The prototype fabrication had the following steps: (i) Cutting the inner and outer fabric into specifically-shaped panels as shown in Figure S2(a), (ii) sewing the inner fabric pieces together to form an inner jacket, (iii) wrapping the aerogel securely around the inner jacket, (iv) sewing the outer fabric pieces and zipper together over the aerogel layer and with the inner jacket, and (v) sewing the collar onto the neck of the assembly to complete the product. Straight stitch should not be applied as straight stitch can tear the fabric easily because neoprene and nylon are stretchable. Hence, the zig-zag stitch method is preferred. The zipper was applied to allow the military canteen bottle to be inserted and removed easily from the insulated jacket. The collar was used to reinforce the neck area. The components come together to form a final thermal jacket are shown in Figure S2(b).



(**a**) (**b**)

Figure 2. (**a**) Sketch of the insulated jacket and (**b**) final insulated jacket on the military canteen bottle.

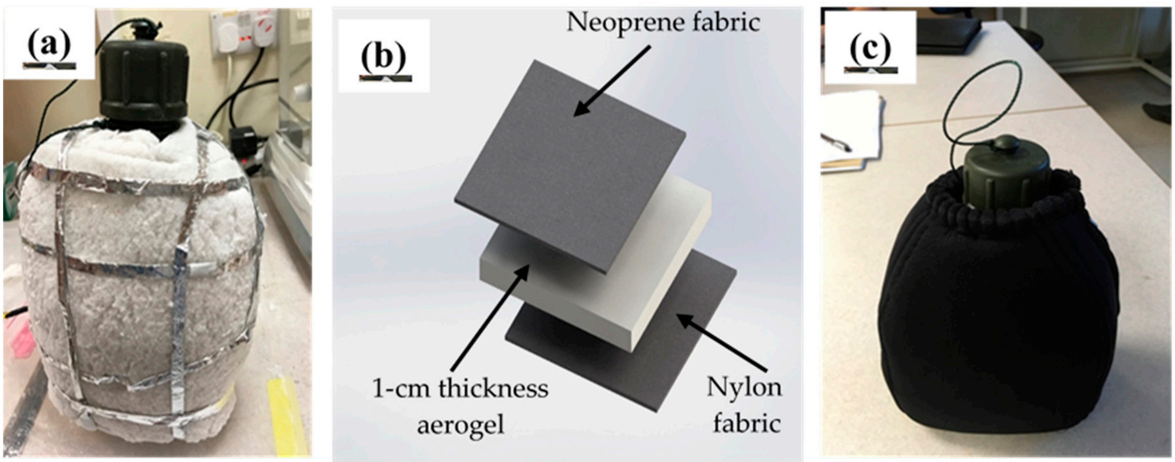


Figure 3. (**a**) Prototype 1 of the water canteen bottle wrapped with recycled cellulose aerogel, (**b**) proposed sandwich structure of the fabric embedded with the cellulose aerogel, and (**c**) water canteen bottle wrapped with a thermal jacket using the cellulose aerogel. The details of the design of sandwich structures and prototype fabrication process of the thermal jacket can be found in Supplements S1 and S2.

Figure S4 below compares the heat insulation performance of the water canteen bottle wrapped with the cellulose aerogel (Prototype 1) with the commercial bottle FLOE, the vacuum flask and the military canteen bottle without any insulating material. It can be observed that the cellulose-aerogel insulated water canteen bottle achieved the similar heat insulation performance of the vacuum flask and performed much better than the FLOE bottle and the military canteen bottle without any insulating material by a significant margin. Compared with the vacuum flask and the cellulose-aerogel insulated water canteen bottle, the vacuum flask posed some concerns in terms of its heavier weight and higher cost as can be seen in Table S1. It is very interesting that the heat insulation performance of the prototype 1 in this work and the prototype in Figure S2 had almost the same results shown in Figure S4.

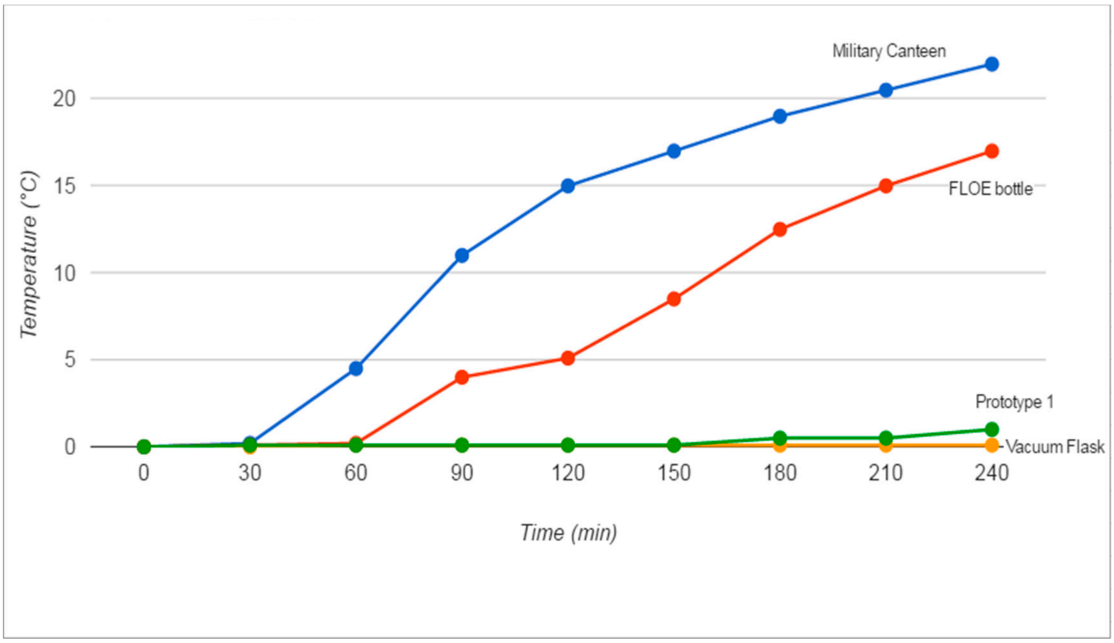


Figure 4. Heat insulation performance of the water canteen bottle wrapped with the cellulose aerogel (Prototype 1) and other commercial thermal bottles.

Table 1. Comparison among the commercial heat insulation bottles and the water canteen bottle wrapped with the cellulose aerogel.

Type	Hydro Vacuum Flask [24]	FLOE Bottle [25]	Water Canteen Wrapped With the Cellulose Aerogel (1.0 L)
Capacity	1.2 L	0.5 L	1.0 L
Insulation method	Vacuum Insulated	Vacuum Insulated	Insulated by high density of air pockets
Weight	900 g	500 g	360 g
Cost	$45	$49.90	$1.52 (Water Canteen) + $0.12 (Cellulose) + 9.67 (Electric and Water) + Miscellaneous + others = ~ $24

The cost estimation of the cellulose aerogel preparation in Singapore dollars was derived as below.

- The chemicals used were 2.4 g of Kymene and around 75 mL of trimethoxymethylsilane (MTMS) chemical.
- Two samples of the 1.0 wt.% cellulose aerogels with 1.5 cm thickness were required to completely wrap around the water canteen. Therefore, 27 g of cellulose was used totally.

- Recycled cellulose costs around $4.36 /kg and 22 g of cellulose can cost around 12 cents.
- Electric and water bills included using the ultrasonicator machine, fridge, freeze dryer and the oven. Utilizing the fridge used 0.4 kW for 12 h = 4.8 kWh, the freeze dryer for 48 h at 0.5 kW = 24 kWh, the oven for a total of 15 h which included curing and hydrophobic treatment at 1.2 kW = 18 kWh, the sonicator for 30 min at 2 kW = 1 kWh. In total, 47.8 kWh were utilized. Since the tariff for electricity is 20.20 cents/kWh accurate for January to March 2017 period [4], the total energy costs were $9.66.
- The total amount of water used was approximately 4 L= 1.17/1000 × 4 = $0.00468. The tariffs for water in Singapore were $1.17 /$m^3$ [1].

Reference

1. SP group. Available online: https://www.spgroup.com.sg/home (accessed on 24 May 2019).