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OPTIMISATION OF THERMAL MANAGEMENT OF LI-ION CELLS WITH PHASE CHANGE MATERIALS

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1. INTRODUCTION

Li-Ion cells will promote the exploitation of renewable energy sources, playing an important role in helping societies to reach their emissions reduction targets. They do this in three ways, by balancing the mismatch between electricity production and demand, by permitting the use of distributed renewable energy systems, and by providing power backup. However, while Li-Ion cells are characterised by high voltages, high energy/power density and moderate operating life, their performance is quite sensitive to temperature [1]–[3]. Adverse temperature operation leads to capacity fade, faster ageing effect and thermal runaway. Therefore, Li-Ion cells should operate in the range of 25-40°C. Also, a minimal temperature disuniformity within the cell [3], [4] can avoid localised cell deterioration and battery pack performance defects.

Four main Thermal Management Systems (TMS) for Li-Ion cells are reported in literature: air-cooling, liquid-cooling, flow/pool boiling and Phase Change Materials (PCM). Among these, PCMs can be an effective TMS. When used as a passive cooling technique, they are characterised by moderate capital and O&M costs, compactness, high efficiency and low parasitic power consumption [5]. However, when Li-Ion cells are operated continuously at high discharge rates, PCMs could recover only part of their latent heat potential by solidification and this can lead to thermal runaway after a certain number of cycles. Therefore, details on the electricity demand are essential.

This research project focuses on the optimisation of Li-Ion cells' TMS by PCM. Different designs of aluminum-sintered blocks filled with octadecane as PCM are tested to determine the TMS benefits on the Li-Ion cells' electrical and thermal performance.

2. METHODOLOGY

Two kinds of tests were conducted: single cycles and stress sequences. Single cycles consisted in single charge-discharge cycles at constant charge rate (CR) of 1C and discharge rate (DR) of 1, 2, 3, 4, 5 C with resting periods after each charge and discharge to cool down the PCM TMS Li-Ion cell system. These tests were designed to investigate the effect of DR on PCM effectiveness as TMS in the case of intermittent demands (e.g. power tools, electronics, stationary electricity storage). In the stress sequences, Li-Ion cells were cycled 10 consecutive times at CR=DR=3C without resting periods, similar to the constant fast charge-discharge load present in automotive applications.

By keeping track of Li-Ion cell voltage, current, surface temperatures (4 RTD PT100 sensors, 2 per side) and heat flux (one sensor on one side), the authors evaluated discharge capacity, discharge electrical energy, average/maximum/minimum Li-Ion cell's surface temperatures, Li-Ion cell's surface temperature disuniformity, volumetric heat generation (being the sum of the enthalpy variation and heat losses towards the surroundings) and electro-chemical efficiency. To compare the benefits of the PCM TMS proposed, tests were run without PCM (i.e. air natural convection) and with PCM as TMS. All devices were operated by LabVIEW code and data were sampled at 0.25 Hz.

The Li-Ion pouch cells tested were AKKU300 characterised by nominal voltage of 3.7 V, capacity of 300 mAh, dimensions 32 mm × 22 mm × 4.8 mm, mass 7.02 gr, and specific heat capacity of 1479 ± 205 J/kg K. The batteries were cycled using an HM8143 Arbitrary Power Supply, which could be operated as power supply (cell charge) and

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electronic load (cell discharge). The PCM selected for these tests was a 99% pure Octadecane, a paraffin characterised by melting temperature in the range of 26-29°C, specific latent heat of 250 kJ/kg, thermal conductivity of 0.144 W/m K, specific heat capacity of 1990 J/kg K and solid density of 777 kg/m^3. The PCM was provided by Sigma Aldrich (O652) and its thermo-physical properties were measured at the HSLU Thermal Energy Storage Competence Center.

The passive PCM TMS were composed of aluminum blocks designed by the authors and sintered by Direct Metal Laser Sintering (DMLS) technique using a Concept Laser Mlab Cusing. The aluminum powder was a Concept Laser CL 31AL 86% Al pure of equivalent thermal conductivity around 120-180 W/m K. Two designs were proposed: simple and finned (**Fig. *1***). In the simple design, the PCM was located within the two lateral pockets while the Li-Ion pouch cell was positioned in the center. Thermal paste provided by Electrolube was used to minimise the thermal contact resistance between Li-Ion cell and aluminum block. The masses of Al and octadecane were respectively 18.3 (63%) and 10.55 (37%) gr. The finned design was an improved version of the simple one, characterised by fins surrounding the Li-Ion cells and enclosing the PCM in separate pockets. This model should improve the equivalent thermal conductivity of the PCM TMS and foster the PCM crystallization by solidification while decreasing the energy density and increasing the total TMS weight. In this design, the masses of Al and octadecane were respectively 36.6 (74%) and 12.85 (26%) gr. Moreover, to evaluate the PCM TMS cooling effectiveness without the contribution of external air natural convection, the blocks were located at the center of a thermally-insulating box made by ethylene propylene rubber foam of external dimensions 70 mm × 75 mm × 100 mm and thermal conductivity at 25°C of 0.037 W/m K.

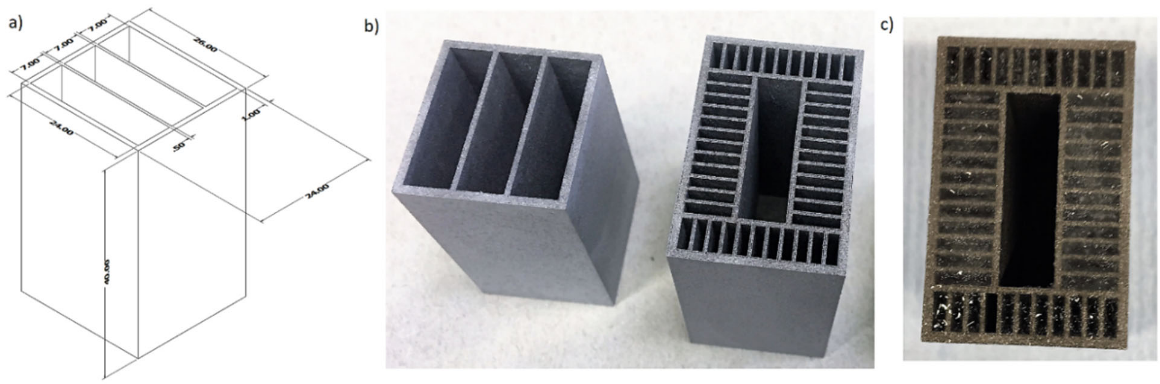

Fig. 1 Aluminum-sintered TMS blocks: a) simple design dimensions in mm, b) simple (left) and finned (right) designs, c) finned design with octadecane located.

3. RESULTS

The results of the stress sequences are reported here as these tests show the PCM TMS effectiveness when working in the most extreme conditions, being continuous operation and no cooling periods. In ***Fig. 2***, the temperature profiles for Li-Ion cell and PCM are reported for air natural convection, the PCM TMS simple and finned designs. During these tests, the median temperature of the lab was 22.8°C.

Compared to air natural convection, where the cell experienced maximum temperatures up to 42°C, the TMS PCM simple design was capable to keep the cell in the range of 26-32°C once the PCM started melting. This condition was reached in between the second and the third cycles. Also, the maximum surface temperature disuniformity was always kept lower than 1.33°C compared to 2.09°C of air natural convection. It must be pointed out that the lower temperatures of the PCM TMS cooled Li-Ion cell led to a decrease of discharge capacity and energy compared to the air-cooled cell of 28.3% and 28.7%. However, this operating condition would lead to potentially 27% longer Li-Ion cell operating life, as demonstrated in a study by Waldmann et al. [3]. The same test was reproduced using the PCM TMS finned design. The Li-Ion cell was kept at 25-32°C while the maximum surface temperature disuniformity was kept lower than 1.6°C. As with the previous design, the lower temperatures of the PCM TMS cooled Li-Ion cell led to a decrease of discharge capacity and energy compared to the air-cooled cell of respectively 15.4% and 16.2%.

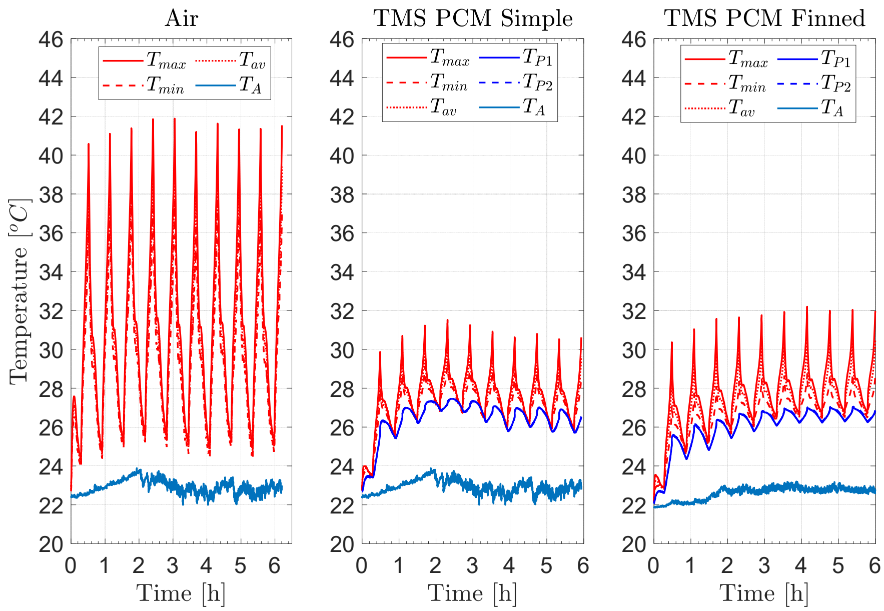

Fig. 2 Stress sequences: 10 consecutive charge-discharge cycles at CR=DR=3C. Air natural convection (left), TMS PCM simple design (center, see **Fig. 1**, a) and finned design (right, see **Fig. 1**, b). For each case, Li-Ion pouch cell (red) minimum, average, maximum temperatures and PCM (blue) temperatures for both pockets are shown.

4. CONCLUSIONS

Thermal management of Li-Ion 300-mAh pouch cells by Passive PCM cooling has been investigated. Results of stress sequences consisting of 10 consecutive charge CCCV-discharge CC cycles at CR=DR=3C without resting periods for two designs of PCM-filled sintered aluminum TMS blocks have been proposed and compared to air natural convection. The simple and finned designs lead to average cell surface temperatures respectively in the range of 26-32°C and 25-32°C compared to peaks of 42°C for air natural convection. Also, surface temperature disuniformities lower than 1.33°C and 1.6°C were measured for respectively simple and finned designs compared to 2.09°C for air natural convection. Previous literature show that the specific thermal condition obtained by using PCM TMS would potentially lead to 27% longer Li-Ion cell operating life.

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