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Microvascular composites for integrated battery packaging and cooling

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ABSTRACT

Lithium-ion batteries have become the main energy source for hybrid and all-electric vehicles due to their high energy density. However, the incorporation of Li-ion batteries within vehicles presents two unique challenges. First, the batteries must be kept cool during operation to ensure optimal performance. Second, the batteries must be kept safe from damage in the event of a crash, as damaged batteries can develop short circuits that lead to cell overheating and fires. Most electric vehicles address these goals with a heavy, complex battery packaging scheme. Aluminum cooling fins that circulate a coolant are stacked between batteries for thermal management and the batteries are encased in steel for crash protection. Here we propose a more elegant solution using microvascular fiber-reinforced composites. Microvascular composites contain internal channel networks for fluid flow and have shown promise for applications such as self-healing and thermal management [1]. For our packaging scheme, batteries are embedded in structural carbon fiber composites that contain cooling channels. The flow of coolant through the composite provides thermal management, whereas the strong, energy absorbing carbon fiber material can protect batteries in the event of a crash.Cooling simulations carried out with ANSYS Fluent confirm the feasibility of the microvascular packaging scheme. To validate these results, microvascular carbon fiber composites are manufactured using vacuum-assisted resin transfer molding. Microchannels are incorporated using sacrificial fibers placed between fabric layers during layup and removed after cure. Nylon sacrificial fibers are removed mechanically after cure, whereas sacrificial polylactide (PLA) fibers are removed through vaporization at elevated temperature [1]. To create more complex channels such as curved and branching channels, a sheet of sacrificial PLA is cut in the desired shape by a laser cutter. The patterned sheets are then placed between fabric layers and vaporized after cure.Cooling performance of microvascular composite packaging is experimentally determined for battery simulated conditions. The surface temperature of each panel is measured using an IR camera while the panel is exposed to a constant heat flux from below during cooling with a constant flow rate of ethylene glycol coolant. Thermocouples are also employed to track the temperature rise of the coolant through the panel. Good agreement between experimental results and simulations are obtained across a wide range of heat fluxes, coolant flow rates, and channel architectures.Finally, a gradient-based optimization scheme is used to find optimal channel designs for various thermal loads. Objective functions are set to minimize panel temperature, with constraints set for the coolant pressure drop and channel volume fraction. The efficiency of the optimization procedure is enhanced through the use of an interface-enriched generalized finite element method [2] specially developed for the thermal analysis of microvascular media. Flexibility in channel shape is achieved through the use of nonuniform rational B-spline representations.

REFERENCES

[1] Esser-Kahn, A., et al. *Adv. Mater.* 2011, 23, 3654–3658.
[2] Soghrati, S., et al., *Int. J. Heat Mass Transfer*. 2013, 65, 153–164.