INTEGRATED THERMAL MANAGEMENT SOLUTIONS IN COMPOSITE MISSILE SKINS

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Introduction

In many applications, component design is driven by both structural and thermal requirements, among other things. Often, composite materials are attractive in structural applications due to their stiffness, strength, and density properties. More specifically, fiber-reinforced composites have the ability to be tailored to specific applications. Fibers can be placed into the appropriate orientations to optimize structural capacity both from a strength and stiffness standpoint. Their thermal properties, however, can often lead to problems in designs where thermal management or heat dissipation is a concern. Thermoset polymers tend to have very low thermal conductivities, and even though the carbon fibers have high thermal conductivity along their lengths (>10 W/m-°C) [1], they have very low conductivity in the radial direction (<2 W/m-°C). Coupling these two materials can often lead to a laminate that has a through-thickness thermal conductivity of less than 1 W/m-°C. These properties are well documented in the open literature [1-3].

For filament-wound carbon fiber reinforced epoxy composites, a goal of 20 W/m-K was established for the through-thickness thermal conductivity.

Experimentation

Initially, experiments were conducted to disperse multi wall carbon nanotubes (MWCNTs) in epoxy and create a composite laminate with high through thickness thermal conductivity. Results showed that this method would not lead to the levels of conductivity required. For loading levels that are conducive to filament winding (< 3000 cP), thermal conductivities were on the order of 0.2 W/mK. This is in agreement with results from other researchers [4].

Material	**Thermal Conductivity** (W/mK)
Epoxy baseline	.17
1 vol % MWCNT	.19
5 vol % MWCNT	.26

Table 1 ASTM E1225 thermal conductivity results with randomly dispersed MWCNTs

The minimal increase in thermal conductivity from loadings of MWCNTs can be attributed to interfacial resistance. These initial studies made it evident that increasing the through-thickness thermal conductivity will require a continuous path through the laminate with minimal interfaces to accommodate phonon and electron transfer.

Several methods are considered for creating a continuous conduction path through the composite laminate: Z-pinning and transient liquid phase sintering (TLPS) polymers will be discussed here.

Z-Pinning

Z-pinning is the insertion of high-thermal-conductivity pins through the composite laminate. For filament winding, pins ranging from .030 to .1 inch diameter are considered. The pins are made from pitch based carbon fibers and pyrolytic graphite and are supported in the winding mandrel with foam block inserts. See Fig. 2.

Pitch based carbon fibers were used to produce pins that were subsequently filament wound into an IM7/Epoxy laminate. Copper pins were also used to establish a baseline for comparison. Thermal conductivity test coupons were cut from the cured laminate for comparative rod testing. Initial results from this work are shown in table 2.

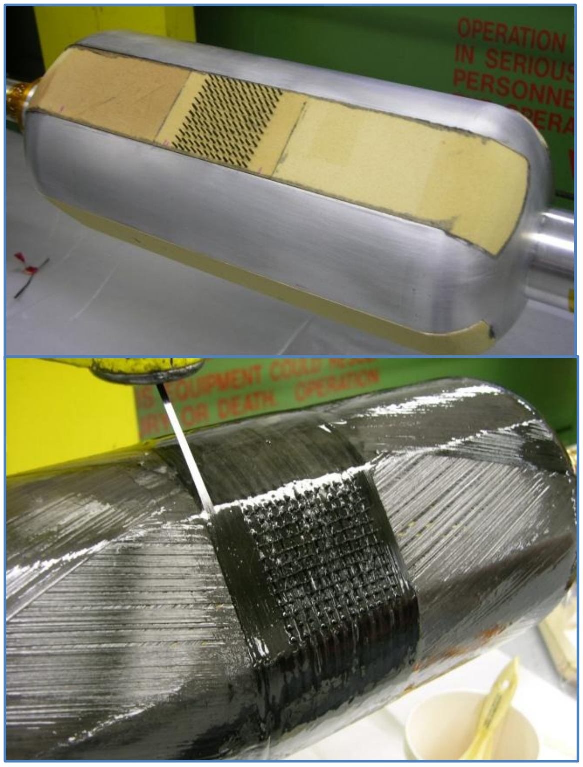

Figure 1. Filament winding over high-conductivity Z-pins. Bare mandrel with Z-pins inserted into foam blocks (top). Winding carbon fiber over Z-pins (bottom).

Configuration	Pin Diameter	Pin Spacing	σ
	(in)	(in)	(W/mK)
IM7/Epoxy Baseline	--	--	0.68
IM7/Epoxy Pitch Pins	0.05	0.198	3.11
IM7/Epoxy Pitch Pins	0.05	0.228	3.09
IM7/Epoxy Cu Pins	0.063	0.228	3.7
IM7/Epoxy Cu Pins	0.063	0.286	2.88

Table 2 Results of ASTM E1225 thermal conductivity testing for Z=pinned composites

TLPS

Another method under development to increase the through-thickness conductivity of composite laminates is TLPS polymers. TLPS involves the integration of metallic particles into the epoxy matrix before fabrication of the composite. The metallic particles consist of at least one low melting point phase that is designed to melt during the epoxy cure. The molten metal wets the other particles and creates a conductive path upon solidification.

Results from winding of this material into a composite laminate led to minor increases in thermal conductivity. The minimal improvement was attributed to filtering of the metallic particles by the carbon fiber tow. An EDX image illustrates this in Figure 2.

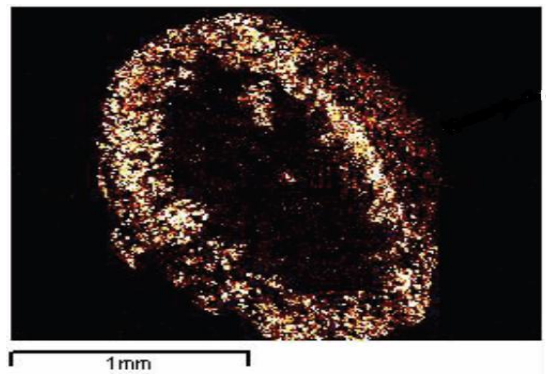

Figure 2. EDX image of metallic particles from TLPS surrounding a carbon fiber tow bundle

Conclusions

Methods for improving the through-thickness thermal conductivity of carbon fiber reinforced epoxy are under evaluation. Initial results show promise but fall well short of the 20 W/mK goal. Processing trials and material formulation will continue in an effort to improve the properties of these materials.

References

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