HOW TO MAKE HIGH-PERFORMANCE STRUCTURAL COMPOSITES MULTIFUNCTIONAL?

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1 Introduction
One of the major concerns in design of aircraft composite structures is the impact damage resistance, especially due to low-velocity impact. The interleaf-toughening concept has been successfully developed to increase the damage resistance by using thermoplastic films or textile veils. However, as the composites are toughened and their use increases in aircraft structures, there comes the need for the Electro Magnetic Interference (EMI) shielding and lightning strike protection, because the materials are electrically isolated compared to their metallic counterpart.

In this paper we present a new approach to simultaneously improve the electric conductivity and the impact damage resistance of the carbon-fiber reinforced composite for aircraft application. By applying the interlayer-toughening technology on these composite, electrically function-added interleaf materials are developed, which on one hand provides significant toughening efficiency, and on the other hand, it functions as a tough and flexible conductor through its surface loading of nano-size electrical conductive fillers [1].

2 Interleaf Materials and Surface Loading
Aerospace-grade carbon fiber epoxy prepreg material was used in this study. One of the interleaf materials was thermoplastic, amorphous phenolphthalein poly ether ketone (PEK-C) film, which was additionally perforated. Another one was a textile veil made of nylon. Both of them are the proprietary trial-products of LAC/ACC. The conductive filler used was silver nanowires (AgNWs). The AgNWs were firstly dispersed in an isopropanol to prepare coating slurry. The film or veil was then dipped in the slurry, followed by a drying process to produce a surfaced-loaded interleaf. The loading level, i.e. the areal density of the AgNWs loaded onto the PEK-C film, was about 1.18 g/m². The electrical percolation threshold of the surface-loaded films was about 0.3 g/m². Generally, when the surface-loading level was higher than 0.75 g/m², the surface resistivity was typically lower than 4.2 Ω/sq.

For the AgNWs-loaded veil, at an areal density of 0.65 g/m², the electrical resistivity is 33 Ω/sq and at a density of 1.5 g/m², the resistivity decreases significantly to 5Ω/sq. The decreasing trend is then leveled off with the curve turning asymptotic to 2Ω/sq. When the areal density is higher than 2 g/m², the surface resistivity becomes very small, typically less than 2 Ω/sq. Both the AgNWs-loaded film and veil is apparently electrically highly conductive.

3 Electrical Conductivity of the Interleaved Composites
When the plain PEK-C films or nylon veils are interleaved, it does not affect the in-plane electric resistivity along the fiber direction (Rs) for all the composites studied, they all are about 0.004 Ω•cm, maintaining the intrinsic conductivity of the carbon fibers.

However, for the plain film interleaved, the in-plane resistivity perpendicular to the fiber direction (Rv) is slightly increased from 4.68 to 5.5 Ω•cm, and the through-thickness resistivity (Rt) is significantly increased from 8.18 to 4400 Ω•cm. If the film loaded with AgNWs, a significant decrease in Rt is found, from 4.68 Ω•cm for the control to 0.067 Ω•cm.

For the samples interleaved with AgNWs-loaded veils, the Rt is significantly decreased.
from 4.68 to 0.039 Ω•cm, and the $R_z$ decreases from 8.18 to 0.722 Ω•cm. These results are obviously due to the high conductivity of the interleaves loaded with AgNWs. The decrease in $R_z$ is particularly important because the conductive layers can be used to provide a sufficient lightning current pathway to protect the composite airframes.

4 Interlaminar Fracture Toughness Properties
The interlaminar fracture toughness in terms of the Mode I ($G_{IC}$) and Mode II ($G_{IIIC}$) was studied. Interleaving of PEK-C film resulted in improved fracture toughness. The $G_{IC}$ is generally increased from about 300 to 400 J/m$^2$, whereas the $G_{IIIC}$ increases from 718 to 1344 J/m$^2$ for the interleaved one and up to 1578 J/m$^2$ for those loaded with the AgNWs. A similar trend was also found in the veil interleaved samples. Compared to the control, improvement in $G_{IC}$ is about 120%, whereas $G_{IIIC}$ is increased by over 200%, from 718 to 2410 J/m$^2$ for the plain veil interleaved, and 2345 J/m$^2$ for the AgNWs-loaded veils. These results are encouraging, which demonstrate that the interlayer-toughening efficiency is completely maintained after the AgNWs loading.

5 Conclusion
A highly electrical conductive and highly toughened carbon-fiber composite has been developed and its potential demonstrated for EMI shielding and lightning strike protection of aircraft. The key component for the electrical function-integration is the use of interleaf films or veils surface-loaded with AgNWs. The interleaf, on one hand, is a proven concept for toughening; on the other hand, it functions as a mechanical carrier for surface-loading AgNWs. By interleaving the material into the carbon fiber laminates, both the fracture toughness and electrical conductivity have been improved simultaneously. It seems reasonable to expect that, this technology could potentially offer the traditional structural composite laminates much unique function integration such as thermal conductivity, active damping properties, sensing properties and fire retardant properties etc. Further investigations are underway.

References