CARBON FIBRE COMPOSITES WITH MULTI-NANOFILLERS FOR LIGHTNING STRIKE PROTECTION

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ABSTRACT

Lightning strike is one of the most powerful forces of nature that strikes commercial aircraft more than once a year. There have been no catastrophic failure reported so far, however, lighting can also damage the composite aircraft structures like paint burnt, fibre damaged, and layer removed due to an inadequate or inappropriate design of protection finish. Carbon fibre reinforced polymer (CFRP) composites, which are essential light-weight structural materials due to their great combination of high strength and modulus with low density, considerably increase applying in various industrial applications, including automobile, civil, aeronautical, and aerospace applications. The major two aircraft manufacturing companies do also use composite materials approximately 50% and 53% of its structural weight in Boeing B787 and Airbus A350 [1], respectively. However, electrical and thermal conductivities of CFRP are relatively low in through-thickness direction compare to conventional metal alloy structures that are vulnerable to lightning strike damage. Therefore, the development of out-of-plane electrical and thermal conductivities is required for lightning strike protection (LSP) applications in aircraft structures to solve this parasitic electrical and thermal management issues such as discharging lightning current away from critical areas and shielding against electromagnetic interference (EMI). Due to the effect of electromagnetic interference (EMI), it can interfere and degrade avionic equipment performances or even malfunctions. The internal heat creation must promptly dissipate to the outside surroundings before the limitation of composite materials has been reached that subject to overheat and failure. In the aerospace industry, the solution for CFRP composites recently depends on metallic material structures that are essentially in the form of metallic mesh and expanded foil made of copper and aluminum. They present high conductivity and heat of vaporization that is necessary condition to manage with massive current levels of lightning strike. However, they are comparatively heavy, less corrosion resistance, and weakening by the adjacent materials between metals and composites.

Due to the current innovation and unique features of nano-materials, many researchers have developed directions of cognitive and applied works on nanocomposite materials, especially on polymer nano-reinforcement composites. The advantages of polymer nanocomposites are the improvement in mechanical and functional properties including thermal and electrical conductivities introducing composite materials into new applications. The poor and anisotropic thermal conductivities of CFRPs exhibit issues for the aerospace industry so the concentric cylindrical structure of CNTs with high aspect ratio, is an alternative nanoparticles for CFRP composites enhancement. It efficiently promotes phonon transport because of wider range of phonon frequencies but less phonon scattering across adjacent fibres in the out-of-plane direction, supporting an effective thermal conductivities along their axes [2]. There are several methods to incorporate CNTs into carbon fibre composites such as resin infiltration method, spraying onto prepregs, and growing CNTs on carbon fibre surfaces. The good quality of CNTs nanoparticles dispersion in polymer matrix are expected to elevate multi-functional properties including mechanical, electrical, and thermal properties. Therefore, the extent level of nano-composites distribution and adhesive interactions between the nanofillers and polymer are a considerable criteria to successfully achieve novel materials. Due to the high probability of nanotube aggregates in polymer matrix or the weight increases with CNTs spraying on the surface, the direct synthesis of CNTs on carbon fiber (CF) substrate by chemical vapour deposition (CVD) is another effective technique.

Based on CVD method, catalyst, gas flow, and reaction temperature are the key parameters of growing CNTs. CVD from gaseous hydrocarbon sources of acetylene (C_2H_2) and methane (CH_4) gases on iron (Fe), Nickel (Ni), and Cobalt (Co) substrates has been presented great promises for the growth of CNTs. Due to this limitation of using gaseous raw materials, providing a great difficulty to apply the technology into the broader variety of other potential feedstocks. Then, solid and liquid carbon sources based on poly(methyl methacrylate) (PMMA) will be apply, which is more convenient and environmental friendly. The additional other materials are freely permitted in composite materials so the material properties can be tailored to suit the needs of each specific application. The reduction of mechanical properties underlying carbon fibers with high CNTs growth temperature of the conventional CVD method can be overcome. There are many nano-sized conductive fillers such as metallic particles and carbon-based additives. Based on the nature of carbons, it is light weight, chemically insert, and electrically and thermally conductive properties that are suitable to use as conductive reinforcement in polymer [3]. The carbonaceous nano-reinforcements have been commonly filled into insulated polymer matrix to innovate novel materials with great combination of mechanical, physical and functional properties enhancement [3]. Among these available carbonaceous fillers, graphene nano-platelets (GnP) and carbon black nano-powders (CB) indicate as appropriate fillers that have an extraordinary physico-chemical properties and great potential to improve polymer at a relatively low filler content [4, 5] .

Graphene nanoplatelets (GnP), which made of a few stacks of graphene layers, display as a potential candidate to boost material properties including mechanical properties, electrical conductivity and thermal conductivity generating new functional and structural composite materials. It reported that the mechanical properties were improved due to the reinforcement graphite nanoplateles in fibre reinforced composites. The adding of GnP paper into multilayer composite laminates were not improving only mechanical properties, but electrical and thermal conductivities were also enhanced providing multifunctional material used for many applications [6]. The additional 0.7 wt% graphene oxide in PVA, resulted in 76% and 62% increase in tensile strength and young's modulus, respectively. The only 0.2 wt% (with respect to the epoxy resin weight) of graphene additives improved the fatigue life and prevented the delamination/bucking of the fibers providing great potential for safety, reliability, and cost effectiveness materials [5]. The bending strength had increased 102 % with the incorporation of 0.5 wt% graphene to carbon/epoxy composites, which changed the failure mechanism from intra-laminar failure to combinational mode of inter- and intra-laminar failures [7]. The GnP coated CFRP composites significantly increased in both mechanical properties and electrical conductivities in out-of-plane direction [8]. On the other hand, carbon black nano-powder (CB) is an amorphous form of carbon with the structure similar to disordered graphite that is generally used as the nano-reinforcement to enhance material properties. The influence of various types and loading of CB was a major parameters improving mechanical properties and electrical conductivities, while an insignificant effect on thermal conductivities of matrix was displayed [9]. The incorporate of carbon black (CB) and a combination of carbon black-nanoclay (CB-NC) in acrylonitrile butadiene styrene–polyaniline (ABS-PANI) had enhanced the tensile strength up to 7.18% and 65.83%, respectively, which was a result of homogeneous dispersion and good interfacial adhesion among CB and matrix [10]. Due to the porous surface of CB, the natural rubber had filled up the pores of CB promoting better interfacial adhesion between rubber and CB and also hinder or impede any deformation occur within the rubber compound, thus, contributing to the increment of mechanical properties of natural rubber compounds, including tensile properties and fatigue life [11]. Due to the aforementioned reason, GnP or CB will be used as the second fillers filling into CF/CNTs to maintain the mechanical properties and boost both electrical and thermal conductivities.

In this study, it aims to overcome the challenges of composite material issues caused by lightning strikes. Therefore, superconductive prepreg with necessary multifunctional properties will be generated for lightning strike protection applications, whilst modifying the uppermost ply of CFRP laminates or replacing metal mesh or foil that is comparatively heavy and weakening the structures. For the fabrication process, the CNTs were synthesized with different catalysts (Fe, Ni, Fe/Ni) coating onto CF substrates with high density and great quality of CNTs. Then, carbon-based nanoparticles will be added into CNTs to fill pores and spaces using spin coating in order to maintain or improve the mechanical properties of CFRP composites. CFRP composites were then fabricated by VARTM

(Vacuum-assisted resin transfer molding) process with only the outmost plies modification. A noticeable synergetic effect of filling carbonaceous nano-additives on growth CNTs/CF cloth has substantially enhanced through-thickness functional properties of CFRP composite by creating varied phonon transport and electron transfer conductive pathways between fibres and also strengthening of structural properties. The development of synthesis and fabrication for multi-functional carbon fibre composites is explored to encounter with lightning strike, EMI, and structural damage issue during service conditions. Therefore, the new commercial carbon fibre composites with high electrical and thermal functionalities in polymer sizing offers an alternative material for lightning strike protection (LSP) applications to open up new opportunities for innovation and industrial applications.

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REFERENCES

[1] P. Cervellera, The Evolving Role of Computer-Aided Engineering: A Case Study in the Aeronautical Structural Design, *Innovation in Product Design: From CAD to Virtual Prototyping*, M. Bordegoni and C. Rizzi, eds., London: Springer London, 2011, pp. 97-115.

[2] Q. Zhang, J. Liu, R. Sager *et al.*, Hierarchical composites of carbon nanotubes on carbon fiber: Influence of growth condition on fiber tensile properties, *Composites Science and Technology*, vol. 69, no. 5, 2008, pp. 594-601, (doi: 10.1016/j.compscitech.2008.12.002).

[3] D. D. L. Chung, Electrical applications of carbon materials, *Journal of Materials Science*, vol. 39, no. 8, 2004/04/01, 2004, pp. 2645-2661, (doi: 10.1023/B:JMSC.0000021439.18202.ea).

[4] A. Dong, Z. Zhiyi, J. Haixiang *et al.*, Effect of carbon black nature on dynamic mechanical properties and reinforcement of nr vulcanization by latex techniques, *Rubber Chemistry and Technology*, 2017, (doi: 10.5254/rct.17.84828).

[5] F. Yavari, M. A. Rafiee, J. Rafiee *et al.*, Dramatic increase in fatigue life in hierarchical graphene composites, *ACS Applied Materials & Interfaces*, vol. 2, no. 10, 2010/10/27, 2010, pp. 2738-2743, (doi: 10.1021/am100728r).

[6] H. Wu, and L. T. Drzal, Graphene nanoplatelet paper as a light-weight composite with excellent electrical and thermal conductivity and good gas barrier properties, *Carbon*, vol. 50, no. 3, 3, 2012, pp. 1135-1145, (doi: 10.1016/j.carbon.2011.10.026).

[7] A. F. Ávila, L. G. Z. d. O. Peixoto, A. Silva Neto *et al.*, Bending investigation on carbon fiber/epoxy composites nano-modified by graphene, *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 34, no. 3, 2012, pp. 269-275, (doi: 10.1590/S1678-58782012000300007).

[8] W. Qin, F. Vautard, L. T. Drzal *et al.*, Mechanical and electrical properties of carbon fiber composites with incorporation of graphene nanoplatelets at the fiber–matrix interphase, *Composites Part B: Engineering*, vol. 69, 2, 2015, pp. 335-341, (doi: 10.1016/j.compositesb.2014.10.014).

[9] M. Ali Raza, A. Westwood, C. Stirling *et al.*, Effect of nanosized carbon black on the morphology, transport, and mechanical properties of rubbery epoxy and silicone composites, *Journal of Applied Polymer Science*, vol. 126, no. 2, 2012, pp. 641-652, (doi: 10.1002/app.36655).

[10] N. Debnath, V. Panwar, S. Bag *et al.*, Effect of carbon black and nanoclay on mechanical and thermal properties of ABS–PANI/ABS–PPy blends, *Journal of Applied Polymer Science*, vol. 132, no. 38, 2015, pp. n/a-n/a, (doi: 10.1002/app.42577).

[11] H. Ismail, N. F. Omar, and N. Othman, Effect of carbon black loading on curing characteristics and mechanical properties of waste tyre dust/carbon black hybrid filler filled natural rubber compounds, *Journal of Applied Polymer Science*, vol. 121, no. 2, 2011, pp. 1143-1150, (doi: 10.1002/app.33511).