論 文 の 内 容 の 要 旨

Thesis Summary

論文題目　Design and development of polyaniline-based multifunctional structural composite materials

(ポリアニリン系多機能構造用複合材料の設計と開発)

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Multifunctional high-performance, lightweight structural composites are the requirement for aircraft structures to protect them from electromagnetic interference and lightning strike. However, the conventional composite structures have poor performance against these severe threats, which is of concern for the safety of aircraft. Hence, in this research, the novel conductive polymer system has been used to design and develop a high-performance multifunctional lightweight structural composite. This work explores the multi-functionality of structural composite based on novel conductive polymer system, (i.e., polyaniline (PANI), dodecylbenzene sulfonic acid (DBSA), and divinylbenzene (DVB)) using suitable fabrication process.

Emeraldine base form of PANI was doped with DBSA and dispersed in the cross-linking polymer, DVB, to prepare the novel structural conductive polymer system. The developed PANI-based polymer composite is investigated and designed for the multi-functional applications, such as, strain sensing, electromagnetic interference (EMI) shielding, and lightning strike protection, which are the three main pillar of this thesis. A comprehensive study was performed to investigate strain sensing ability of the material, by evaluating following parameters, like (i) sensitivity (ii) working range (iii) hysteresis error, (iv) creep error (v) strain rate change effect (vi) reliability and (vii) thermal stability. It was concluded that the material was able to exhibit a linear relationship between the applied strain and the resistance due to piezoresistive behavior. Different studies also confirmed the reversibility, recoverability and reliability of the sensing performance. Moreover, its application, both as impregnated glass fiber reinforced conductive polymer composites and the conductive layer on glass fiber reinforced polymer composites, were verified. The results show the promising opportunities to use these composite materials as a structural self-sensing stain sensor.

For electromagnetic interference shielding investigation (i) shielding effectiveness (SE), (ii) shielding mechanism, (iii) shield thickness effect, (iv) conductivity effect, (v) permeability and permittivity effects on shielding mechanism are studied for X-band (8.2 – 12.4 GHz) frequency. It is summarized from both theoretical and experimental results that the shielding mechanism of the conductive layer dominated by absorption followed by reflection loss. Both complex permeability and permittivity of the material were estimated using the NRW algorithm. It is found the SE by absorption is almost constant for all thickness; however, its magnitude changes with thickness and conductivity value. This is because the electromagnetic attenuation constant is almost independent of frequency. The tunability of the electrical conductivity of polyaniline composite can be used to design EMI shielding performance according to the requirement. The highest EMI shielding up to ~ 20 dB in X-band with a conductivity value of 95 S/m and thickness of 1.0 mm is reported in this work. Furthermore, the bonded conductive layer on GFRP and CFRP composites showed maximum EMI SE of ~ 17.5 dB and ~ 45 dB with a shield thickness and conductivity of 1 mm and ~ 90 S/m, respectively.

For lightning strike protection, the optimized thickness of the novel conductive polymer system layer was studied. Both CFRP and GFRP composites with the bonded conductive layer were tested with a peak current of - 40 kA. However, GFRP composites are further subjected to - 60 kA, and - 100 kA of peak current. High-speed cameras and ultrasonic tests were used for damage analysis for both FRPs and the conductive layer. It can be summarized from results that a minimum conductive layer thickness of 0.4 mm with 50 S/m of conductivity may be able to protect the composites from the lightning current of -40 kA, with a residual strength of 90%.

This doctoral thesis includes the design and development of polyaniline-based multifunctional structural composite material for aircraft application and demonstrating at least its three functionalities (i) strain sensing (ii) electromagnetic interference shielding, (iii) lightning strike protection. The presented research opens up new opportunities and provides a foundation to further improve the performance and functionalities of the composites without changing their material constitutions. A thin layer of a polyaniline-based conductive layer on composites could improve efficiency by protecting from the EMI noise, lighting strike and also could act as a structural strain sensor.