MECHANICAL AND TRIBOLOGICAL PROPERTIES OF COATED FIBER REINFORCED POLYMER COMPOSITES

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Doctor of Philosophy

By

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Conclusions

This thesis investigated the performance of surface modification of aramid and carbon fiber reinforced epoxy composites. The current study shows that applying chemical treatments and nanoparticle coatings to the fibers has a significant influence on the fiber and its epoxy composites' morphological, physical, thermal, mechanical, and tribological properties. The investigation came to the following major conclusions based on the experimental findings of the physical, thermal, mechanical, and tribological characterization of fibers and FREC.

- Acid treatment of CNTs and aramid fibers using nitric and sulfuric acid introduces carboxyl and hydroxyl groups, which promote stronger chemical interactions between the fibers and CNTs.
- The application of CNT coatings on aramid fibers significantly improves the interfacial bonding and mechanical integration of polymer composites, primarily due to enhanced surface roughness and chemical functionalization achieved through acid treatment.
- CNT-coated aramid fibers show a remarkable 22.9% increase in tensile modulus and 23.3% rise in tensile strength by preventing micro-cracks and delamination, thereby improving the overall load transfer capability.
- The inclusion of CNTs in the composites significantly lowers the specific wear rate by 32.41%, demonstrating their effectiveness in reinforcing the composite's resistance to tribological degradation during operation.
- CNT coatings enhance both the hardness and thermal conductivity of the composites, with increases of 27.27% and 36.56%, respectively, contributing to improved structural stability under mechanical and thermal loading.

- Hybrid CNTs/GO coatings on carbon fibers form a 3D network structure that increases surface roughness, enhances fiber-matrix bonding, and significantly improves mechanical and tribological properties of the composite.
- Compared to individual CNT or GO coatings, hybrid CNTs/GO coatings demonstrate superior enhancements in ILSS (38.73%), flexural strength (30.40%), tensile strength (33.53%), and hardness (32.64%) in fiber-reinforced epoxy composites.
- The hybrid-coated composites also show substantial improvements in fracture toughness (36.36%), tensile modulus (31.66%), and flexural modulus (57.68%) over uncoated or individually coated carbon fiber-reinforced epoxy composites.
- The CNTs/GO hybrid coating contributes to a significant reduction in the specific wear rate of the composite by 42.84%, which is essential for applications requiring high wear resistance and reliability.
- The coefficient of friction (COF) increases with higher normal loads but decreases with elevated temperatures or increased sliding frequency, indicating a complex relationship between operating conditions and frictional behavior.
- Thermal conductivity of the hybrid CNTs/GO-coated composite reaches a maximum of 0.377 W/mK, the highest among tested composites, enhancing heat dissipation and thermal stability under operating conditions.
- SEM analysis of worn surfaces confirms superior fiber-matrix adhesion in the modified composites, revealing minimal surface damage and strong interface bonding, contributing to long-term durability and resistance against microstructural degradation.

- Enhanced erosion resistance in CNT/GO hybrid composites is evidenced by a 44.56% reduction in wear rate compared to uncoated composites, with impact velocity identified as the most critical influencing parameter.
- ANOVA results show that impact velocity contributes 56.53% to erosion wear behavior, followed by impingement angle, whereas discharge rate has the least influence at 4.23%, guiding design under erosive environments.
- The dominant erosion wear mechanisms observed through SEM include matrix-fiber debonding, micro-cutting, and plowing, which were significantly mitigated in hybrid CNT/GO-coated composites compared to uncoated composites.
- The hybrid-coated HCFRE composite exhibited the highest tensile strength (518 MPa) and tensile modulus (33 GPa), marking 33.50% and 32% improvements, respectively, compared to uncoated fiber-reinforced epoxy composites.
- These significant mechanical enhancements are attributed to the synergistic effects of 1D CNTs and 2D GO, forming a robust interconnected network that improves stress transfer and crack resistance throughout the composite.
- The hybrid composite demonstrated maximum performance across mechanical, thermal, and tribological metrics, making it a viable material for aerospace, automobile, and structural applications where high-performance materials are crucial.
- Among the machine learning models ANN, RF, and GBM, the GBM model exhibited the highest predictive accuracy for the coefficient of friction in aramid fiber-reinforced epoxy composites, attaining an impressive R^2 value of 0.92807.
- Key factors influencing the COF include nanoparticle content, sliding frequency, and applied load, as revealed through feature importance analysis, emphasizing the complex relationship between material composition and tribological performance.

- The ML-based approach significantly aids in optimizing composite materials by accurately identifying critical parameters, enabling predictive material design and performance analysis for engineering applications under varying operational conditions.

Future Scope

This study lays the foundation for future researchers to explore into several other aspects of fiber-reinforced polymer composites. Some prospective research directions may involve the following areas:

- Dynamic mechanical analysis (DMA) is a technique used to study the viscoelastic behaviour of polymer composites can be done for the developed Fiber reinforced polymer composites.
- The mechanical behavior of FRPCs can be investigated under both low and elevated temperature conditions to assess thermal stability, interfacial integrity, and structural performance reliability.
- Various machine learning algorithms can be employed to predict and analyze the mechanical and tribological behavior of FRPCs under different conditions.
- The current research encompasses both experimental investigation and preliminary machine learning-based analysis of FRPCs, highlighting the potential for developing advanced numerical models and simulations to predict composite behavior.