EXPERIMENTAL AND COMPUTATIONAL STUDY ON SUSTAINABLE HYBRID NATURAL FIBER COMPOSITES FOR MARINE STRUCTURAL APPLICATIONS

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College : Srinivas Institute of Technology, Valachil, Mangaluru
Branch : Department of Marine Engineering
Guide(s) : Prof. Nithin Joshuva
Student(s) : Mr. Adarsh
Ms. Devayani S N
Mr. Karthik P V)
Mr. Kishan Kumar

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Introduction:

1. In recent years, there has been a growing demand for sustainable and eco-friendly materials in engineering applications. Natural fiber-reinforced composites have emerged as a promising alternative to conventional synthetic materials due to their biodegradability, low cost, and lightweight nature. Among these, hemp and jute fibers are widely used because of their good mechanical properties and availability.
2. However, natural fibers face challenges such as poor bonding with polymer matrices and sensitivity to moisture, which limits their performance. To overcome these issues, hybridization and nanoparticle reinforcement techniques are adopted.
3. This project focuses on developing hybrid composites using hemp and jute fibers combined with epoxy resin. Additionally, nano-fillers such as titanium dioxide (TiO_2) and graphene are incorporated to enhance mechanical strength, vibration damping, and acoustic performance.
4. Experimental tests such as tensile, flexural, acoustic, and vibration analysis are conducted to evaluate performance. Furthermore, Finite Element Analysis (FEA) using ANSYS is performed to validate experimental results.
5. The study aims to develop lightweight, durable, and environmentally friendly composite materials suitable for marine and structural applications.

Objectives:

1. To fabricate hybrid composites using hemp and jute fibers.
2. To enhance composite properties using graphene and TiO_2 nanoparticles.
3. To evaluate tensile and flexural strength of composites.
4. To analyze vibration and acoustic performance.
5. To perform ANSYS-based FEA simulations.
6. To compare experimental and computational results.

Methodology:

The project methodology involves both experimental and computational approaches.
First, raw materials such as hemp fiber, jute fiber, epoxy resin (LY556), and hardener (HY951) are collected. The fibers are treated using NaOH solution to improve bonding characteristics.
Next, composite laminates are fabricated using the hand lay-up method. The fibers are arranged in alternating layers (jute and hemp), and epoxy resin is applied uniformly. Nano-fillers such as TiO_2 and graphene are added in specific compositions to prepare different samples.

Four composite samples are fabricated:

1. Hemp + Jute
2. Hemp + Jute + TiO_2
3. Hemp + Jute + Graphene
4. Hemp + Jute + TiO_2 + Graphene

After fabrication, the composites are cured for 24 hours. The samples are then cut into required dimensions using CNC machining based on ASTM standards.
Various tests are conducted including tensile testing, flexural testing, acoustic testing, and vibration analysis. These tests help evaluate strength, stiffness, sound absorption, and damping properties.
Additionally, Finite Element Analysis (FEA) is performed using ANSYS to simulate stress distribution and deformation behavior. The simulation results are compared with experimental findings for validation.

Result and Conclusion:

The results show that composite performance varies based on reinforcement type.

1. The plain Hemp–Jute composite exhibited the highest tensile strength and stiffness. The addition of TiO_2 improved flexural strength and stiffness significantly. Graphene alone showed limited improvement in mechanical properties.
2. The combination of TiO_2 and graphene resulted in the highest flexural performance but reduced tensile strength.
3. Acoustic testing revealed that natural fiber composites provide good sound absorption, especially at higher frequencies. The H/J composite showed the best overall acoustic performance.

4. Vibration analysis indicated that TiO_2 improves stiffness, while the plain composite offers better damping.
5. FEA results from ANSYS closely matched experimental data, validating the computational model.
6. Overall, hybrid natural fiber composites show strong potential as sustainable materials for engineering applications.

References:

1. Lokesh et al. (2025) – Hybrid composites study
2. Senthilkumar et al. (2020) – Jute composite analysis
3. Dahal et al. (2022) – Hemp composites review
4. Ramu & Senthilkumar (2022) – Fabrication techniques
5. Vinoth et al. (2022) – Fiber treatment effects

Future Scope:

The future scope of this project includes:

1. Future work can focus on improving the performance of natural fiber composites through advanced material modifications.
2. Different combinations of natural fibers can be explored to optimize mechanical and acoustic properties.
3. Advanced nano-fillers and hybrid reinforcement techniques can be used to further enhance strength and durability.
4. Improved fabrication techniques such as vacuum infusion and compression molding can reduce defects and improve consistency.
5. Long-term durability studies under marine conditions such as moisture, saltwater, and UV exposure can be conducted.
6. The use of biodegradable resins can further increase sustainability.
7. Machine learning and optimization techniques can be used to predict composite behavior.
8. Industrial-scale production methods can be developed for commercial applications.
9. These improvements will help expand the use of natural fiber composites in marine, aerospace, and automotive industries.