Simulation study on mechanical properties of a sustainable alternative material for electric cable cover

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Abstract: PVC cables, insulation wires have been a major contributor for total plastic waste generated. These cables are difficult to reuse. This report investigates on the PVC cables and finding its replacement with natural fibers reinforced polymer composites reducing 3% of total plastic waste. Plastic waste reduction and reuse has been a major outlook by researchers worldwide. In this report we have considered various natural fibers sandwiched with a matrix film to form a newer biodegradable product. Cables are further analyzed in ANSYS Workbench to check for their mechanical properties and characteristics in real time application.

1. INTRODUCTION

Environmentally sustainable materials, products and processes are greatly noticed not specifically to the scientific forums but also by various industrial organizations due to surge in the extensive use of non-renewable resources, in this case, non-biodegradable polymer products. Polymers are extensively used in almost every form of products in day to day usage from complex structures used in electronic components, industrial equipment, etc. to simple applications like toys, insulating cables, etc. It’s widely employed because of its lightweight, low water absorption index, high strength, and stiffness properties. Existing materials, synthetic fibers like nylon, polyethylene, and polyvinyl chloride are widely used as a reinforcement of polymer. At present, due to the Massive amount of non-biodegradable waste generation and an increase in carbon footprint, there is a need to search for an alternative that is biodegradable with similar properties as that seen in polymers. In recent years, research and development are more focused on natural fibers reinforced polymer composites (NFRPC’s), that are proved as an alternative fiber to its synthetic counterpart. Research study is being carried out at different parts of the world to meet up with the environmental concerns by materials and composites prepared using plant fibers. In this case natural fibers reinforced polymer composites and plant fibers composites are of great interest which can provide similar properties and characteristics at a convenient cost [1]. These types of plant fibers also have some disadvantages when considered as an insulation material, such as less durability due to their vulnerability towards heat and moisture developed in the surroundings, development of cracks due to swelling and volumetric changes in the cables. To overcome the drawbacks of NFRPC’s, treatments with alkali, silane and various water-repelling agents should be used [2]. Extensive study related with mechanical properties have been carried out and corresponding simulations were performed and the comparisons among various plant fiber composites are listed. The most relatable plant fiber composites are considered and simulations are performed to determine its characteristics.
PVC, versatile thermoplastic polymer generally used for cables with density 1.1 to 1.35 g/cm³. PVC finds its huge application due to its low cost, high chemical resistance and good electrical insulation. However, waste produced by electrical cords sums up to 50 million tonnes annually. Most of the waste ends up in the dump yard and very small percent is taken for recycling, according to UN report 2019. India alone generates 2 million tonnes every year. In which 95% of waste is processed for extraction of crude metals such as copper, gold, palladium and etc. But still there is tonnes of plastic waste that is untouched, including the remains after the extraction for crude metals. The untouched plastic wastes are increasing in the landfills and nothing much is done for recycling.

The mechanical properties of PVC as well as the shortlisted natural fibers are cited below in Table 1 and Table 2 respectively.

### Table 1. Mechanical properties of PVC

| Material | Young’s modulus (GPa) | Tensile strength (MPa) | Elongation (%) | Thermal Degradation (°C) | Flexure strength (MPa) |
|----------|-----------------------|------------------------|----------------|--------------------------|-----------------------|
| PVC      | 3.4                   | 26                     | 160(at breakdown) | 250°C - 300°C            | 83                    |

### Table 2. Mechanical properties of shortlisted Natural Fiber [3,4,5].

| Material | Young’s modulus (GPa) | Tensile strength (MPa) | Fibre length (mm) | Elongation (%) | Thermal Degradation (°C) | Flexure strength (MPa) |
|----------|-----------------------|------------------------|-------------------|----------------|--------------------------|-----------------------|
| Abaca    | 41                    | 500-700                | 3000              | 0.25-1.0       | 320-450                  | 40.24                 |
| Bamboo   | 5-25                  | 100-800                | 3                 | 40-90          | 400-700                  | 76.5                  |
| Coir     | 3.44                  | 17.56                  | 1.2               | -              | 290                      | 52.92                 |
| Flax     | 60                    | 345-1035               | 5-900             | 2.7-3.2        | >160                     | 4.3                   |
| Hemp     | 30-60                 | 400-938                | 55                | 3.6-3.8        | 150-260                  | 54                    |
| Jute     | 20-25                 | 393-773                | 1.5-120           | 1.5-1.8        | 240                      | 111.8                 |
| Pineapple| 34.5-82.5             | 400-1000               | 900               | 2.5-3.5        | -                        | 86                    |
| Ramie    | 31.8                  | 630                    | 1200              | -              | 280-350                  | 103                   |
| Sisal    | 17.22                 | 360                    | 900               | 3.58           | 340-380                  | 43                    |
| Coconut  | 0.856                 | 30.6                   | as per density    | 25.44          | 450                      | 46.5                  |

### 2. CAD MODELLING

The cable was designed in CATIA SOFTWARE and further its geometry was improved in ANSYS 18.0. Figure 1(b) depicts the cross-section of the hollow cable model with 3 different layers of natural fiber and matrix. Figure 1(a) depicts the cross-section view of the existing PVC cable.

![Figure 1(a). Cross section view of existing PVC cable](image-url)

![Figure 1(b). Cross section view of proposed PVC cable](image-url)
3. FINITE ELEMENT ANALYSIS

Finite Element Analysis is the suitable method to analyze the problem in virtual reality. It follows to all the prerequisites requirements to make an industry eligible product with best optimization to real time scenarios.

3.1. Static Structural Analysis
Every problem when solved for Finite Element analysis, first step it would be subjected to a case of static structural analysis. Further, the work will be subjected to various other loads and boundary conditions are applied and the analysis is continued.

3.2. Meshing
All meshing process starts with generic auto mesh and then it subjected to refinement according to the geometry of the model with suitable meshing quality and range of element size as shown in figure 2a and figure 2b. An element type of default and relevance center with fine meshing was considered as illustrated in figure 2c. It can be inferred that mesh with uniformity and minimum edge length 0.20mm with an adaptive size function is considered and solved in ANSYS Workbench.

3.3. Boundary Conditions
For total deformation test and tensile test the cable is supported by a fixed support on one end as shown in figure 3c and load will be applied on the other side as shown in figure 3a. During flexural test the fixed supports are assigned to 2 points on the base of the coupon test as depicted in Figure 3d and loading will be at the centre shown in figure 3b.
Following are the FEM analysis results of total deformation (Figure 4a), Von-Mises Equivalent stress (Figure 4b) and flexural strength (Figure 4c) Natural fibers' composite matrix, to substitute conventional PVC cables.

Maximum deformation and Equivalent stress developed in the PVC cable for a load of 500 N are 20.09 mm and 52.22 MPa. Flexural strength for ASTM standard coupon test case for PVC is 2817 MPa for 1000N point load. Now for any material to replace PVC its deformation and stress must be lower than these values.

The analysis results were validated for h-type (element size) and p-type (element order) methods [6,7]. The symmetric nature of the deformation plot depicts the corrective measures of loads and boundary conditions [8,9].

The von-mises stress plot results seem to be accurate based on the convergence theory and compatibility equation which is decided based on the number of iterations carried out for each of the case [10,11].

Static Structural Analysis of Total deformation test of natural fibres and matrix film (PVAc). Shown in Figure 5a to Figure 5e for various materials.
Static Structural Analysis for Tensile test of natural fibres and matrix film (PVAc) for various material cases highlighted in figure 6a to Figure 6e.

Static Structural Analysis for 3-point Flexural Test of natural fibres and matrix film (PVAc) of various materials illustrated in figure 7a to Figure 7e.

Results and comparisons of the finite element analysis of natural fibers and matrix film (PVAc).
Shown in Table 3.

| Material                | Deformation in mm | Stress MPa | Flexural Strength MPa |
|-------------------------|-------------------|------------|-----------------------|
| PVC                     | 20.097            | 52.221     | 2817.3                |
| Abaca and PVAc          | 2.03              | 64.034     | 3205.4                |
| Bamboo and PVAc         | 3.385             | 63.93      | 3148.2                |
| Coir and PVAc           | 14.57             | 58.903     | 3057.6                |
| Hemp and PVAc           | 1.69              | 65.288     | 3239.8                |
| Sisal and PVAc          | 2.543             | 63.982     | 3180                  |

4. CONCLUSION

Analysis on various natural fibers like hemp, coir, abaca, bamboo & sisal we learnt, these fibres have comparable physical properties as existing material PVC for cables. Hemp with young’s modulus of 30-60 GPa has equivalent properties. Composite formed by hemp and PVAc, a bio degradable synthetic resin, was analyzed to be a better replacement for synthetic cables with minimum deformation of 1.69mm, tensile stress 65.288 MPa, flexural stress 3239.8 MPa. This new matrix formed is best substitute for thermoplastic polymer.

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