MODELLING AND ANALYSIS OF COMPOSITE POLYACRYLONITRILE NANOFIBER MATS UTILIZED TO STRENGTHEN MOTORBIKE SIDE PANEL

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Abstract. Computer modelling, analysis of the mechanical properties and development of a nano membrane from composite polyacrylonitrile (PAN) nanofiber mats were proposed in this study. The aim of this experiment is to deposit electrospun nanofibers in stationary and sliding substrates. Due to its ease of setup and ability to mass-produce nanofiber mats, the electrospinning method has grown more popular than other nanofiber production technologies. The collector's design, movement, and form can have an impact on the creation of nanofiber mats. A polyacrylonitrile solution (20 wt%) was developed and it was deposed in both sliding and stationary substrates to create mats. The results of the strength test of the polyacrylonitrile mat and composite polyacrylonitrile epoxy specimen were compared from both sliding and stationary substrates. The mechanical behaviour of the composite polyacrylonitrile nanofiber mats on the side panel of the motorbike was investigated. For this, mathematical modelling of the motorcycle side panel was examined in ANSYS, and the findings were compared to those of standard *Acrylonitrile Butadiene Styrene* (ABS) plastic. According to the results, PAN nanofiber composite surpasses ABS plastic in the yield strength, equivalent stress, and total deformation by 71.25%, 56.37% and 17.68%, respectively. Compared to standard ABS plastic, the PAN nanofiber composite exhibits superior mechanical characteristics, according to the static analysis on ANSYS. Consequently, the PAN nanofiber composite mat may be utilised to substitute ABS plastic in certain applications.

Keywords: Polyacrylonitrile solution, electro spinning, ANSYS, ABS plastic.

Introduction

Nanofibers provide a lot of opportunities for changing things physically and chemically during or after the production process to give them new features [1; 2]. Electrospinning can be used to make nanofibers from polymers in solution and melt form, as well as non-polymeric materials such as ceramics and metals [3]. Electrospinning enables the fabrication of thin fibers ranging in diameter from a few tens to several hundred micrometres from a variety of polymers or polymer mixes [4]. Nanofibers of this kind may be employed in a variety of applications, including air filtration [5; 6], water filtration [7; 8], batteries [9], and biological applications [10]. Polyacrylonitrile is a common precursor material for carbon nanofibers (PAN) [11; 12] . Additionally, this polymer is spendable from the non-toxic solvent dimethyl sulfoxide (DMSO).

Numerous aspects influence the diameters and morphology of electro spun nanofibers. They are the molecular weight of the polymer solution, its viscosity, conductivity, surface tension, concentration, solution flow rate, and distance between the capillary and collection screen, as well as ambient temperature and humidity [13]. The motion and size of the collection screen, as well as the needle gauge size, are all factors to be considered. The produced nanofiber mats are collected from the stationary and sliding substrates for this electrospinning process [14]. Nanofibers produced from electrospinning process have a unique tendency, reducing the diameter of nanofibers leads to increase in the mechanical properties of nanofibers [15; 16].

Rotating collectors, such as the drum and electrodes separated by a gap, can easily produce oriented fibers. Traditionally, unaligned or randomly oriented fibers are gathered on a static substrate such as a grounded metal plate [17]. In most cases, conductive tips are utilized instead of needles, and the tip-to-sample separations are extremely small [18]. Because the fibers do not experience bending instability at such short working distances, they are usually gathered in a more stable jet zone on a sliding substrate, allowing for highly controlled fibre collection. This method has the advantage of allowing micrometre-sized patterns to be produced within the resolution limitations of the collecting linear motion stage [19]. To create aligned nanoparticles in a polymeric fibre, the authors used Scanned Tip Electrospinning Deposition to generate aligned nanofibers [20].

One of the major technical problems of the last decade has been to design and mass produce more efficient materials in all industrial sectors [21-23]. At the moment, there is an active search for new lightweight and reinforced metal-matrix composites [24] for automotive and aerospace applications [25-

27]; novel reinforced metallo-ceramic-matrix composites for the construction sector [28]; novel reinforced metallo-polymer composites with innovative design; and novel reinforced metals-crystals-polymer composite fibers with electromagnetic field protection properties for office applications [29; 30].

The purpose of this experiment is to analyse the deposited nanofibers on sliding and stationary subtracts with a single needle in the electrospinning process, and the simulation results were compared. In fact, nanofibers are involved in automobile applications, so the produced nano fibre mats are implemented in the motorcycle's side panel through ANSYS to test the mechanical behaviour of the polyacrylonitrile nanofiber composite with standard acrylonitrile butadiene styrene (ABS) plastic.

Materials and methods

Polyacrylonitrile is a flexible polymer that is used to fabricate ultra - filtration membranes, hollow fibers for filtration [31], textile fibers, and oxidized PAN fibers, among other things [32; 33]. ABS chains are held closely together by this high attraction, making the material stronger. ABS is also more durable than polystyrene because of the rubbery polybutadiene [34-37]. Two nitrile groups are present on the same vinyl carbon in acrylonitrile derivative. By considering these facts, polyacrylonitrile has been chosen for this experiment.

Filling a tiny glass storage bottle more than half with formic acid was the first step in setting up the polyacrylonitrile solution from polyacrylonitrile (PAN) CAS no: 25014-41-9. Polyacrylonitrile accounts for 20% of the weight of that formic acid. A magnetic stirrer would next be used to stir the mixture. The magnetic stirrer temperature must be set to 40 degrees Celsius at 380 rev/min. Polyacrylonitrile may take up to 6 hours to dissolve in the formic acid. Once fully dissolved in formic acid, the polyacrylonitrile solution would be labelled and stored in a storage bottle.

The electrospinning unit consists of a high-voltage power source, a syringe pump, a spinneret, and a stationary collecting plate. Cover the collector plate with aluminium foil to gather nanofibers. Connect the syringe to the syringe pump and fill it with the produced polyacrylonitrile solution. The distance between the syringe tip and the collector plate has been set at 25 cm. The collecting plate must be linked to the high voltage power supply's positive terminal, and the syringe needle to the negative terminal. The syringe pump speed is set to 0.60 $ml \cdot h^{-1}$. Given below, Figure 1 represents the electrospinning setup with a flat collector plate with high voltage negative power supply and a syringe with positive high voltage supply.

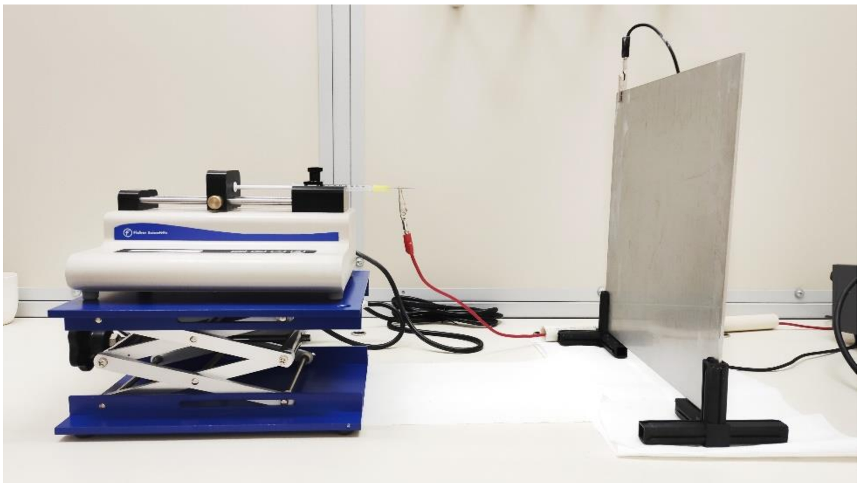

Fig. 1. **Electrospinning setup**

Nanofibers will begin to accumulate on the collector plate as soon as the electrostatic forces counterbalance the surface tension of the polyacrylonitrile solution at critical voltage, and an electrified jet is formed and ejected from the tip. As the electrospinning period proceeds for 16 hours, the thickness of the randomly oriented fibers increases in the stationary collector. In the sliding substrate, the same technique has been for collecting nanofibers, but the sliding collector plate is designed to manually switch back and forth on each side. The nanofibers are carefully labelled and stored for strength testing after all the electrospinning is completed. The electrospinning process parameters are mentioned in Table 1.

Table 1

Electrospinning process parameters

Process parameters	Parameters used
Solution	PAN + N,N-Dimethylformamide
Solution concentration	Polyacrylonitrile 20wt%
Flow rate	0.60 ml·hr^{-1}
Tip to collector distance	25 cm
Collectors	Stationary flat plate and sliding flat plate
Time of Electrospinning	16 hours
Speed of sliding linear plate motion	11 m·s^{-1}

For the strength test, the nanofiber mat was peeled off the aluminium foil and folded into 5 cm long, 1 cm wide, and 0.1 mm thick specimens. Mecmesin's Multi-Test 2.5-i Tensile and Compression Test System was utilized to test the specimens collected from both stationary and sliding substrate. The data from the system is collected using Emperor Software. Emperor was designed to function with Mecmesin's top-of-the-line Multi-Test-i force testing systems alone. The strength test results of the collected pure polyacrylonitrile nanofiber mat are tabulated in Table 2.

Table 2

Strength test results on pure polyacrylonitrile nanofiber mat

Type of collector	Maximum force applied, N	Elongation, mm	Tensile strength, MPa
Stationary	88.5	9.288	10.02
Sliding	146.75	10.176	12.25

Determine the Young's modus of pure epoxy resin to evaluate the strength of the polyacrylonitrile epoxy resin. Once the specimen is placed in the tensile test apparatus, the gap between the holds is set to 30 mm. Four iterations are performed to generate more accurate results and calculate the mean of elongation and tensile strength. Then solidify the polyacrylonitrile nanofiber mat with epoxy resin to create polyacrylonitrile epoxy resin to test its strength. Table 3 shows the strength test results of polyacrylonitrile epoxy resin.

Table 3

Strength test result on polyacrylonitrile epoxy specimen

Type of collector	Maximum force applied, N	Elongation, mm	Tensile strength, MPa
Stationary	313.7	0.316	21.75
Sliding	345.11	0.314	24.88

The mechanical characteristics of pure polyacrylonitrile nanofiber mat must be determined from the numerical simulation for further analysis, which is the primary part of the research. The elastic modulus of the nanofiber mat must be computed for polyacrylonitrile nanofiber mats which are collected from both stationary and sliding substrates.

Young's modulus,

$$E = \frac{\sigma}{\varepsilon} = \frac{F \cdot L}{A \cdot \Delta L} . \tag{1}$$

Equilibrium forces equal to the applied force shared by the fibres and matrix.

$$F_c = F_m + F_f . \tag{2}$$

where F_c – total force of the composite material;
F_m – force taken by matrix;
F_f – force taken by fibre.

Then equation (2) written in the form of stress,

$$\sigma_C A_C = \sigma_m A_m + \sigma_f A_f \quad (3)$$

where A_C – area of cross- section of the composite;
A_m – area of cross- section of the matrix.

Geometry of deformation: total strain in the composite will remain the same as in the matrix fibers,

$$\varepsilon_C = \varepsilon_f = \varepsilon_m \quad (4)$$

The stress–strain relationship of each member is shown as,

$$\sigma_C = E_C \varepsilon_C, \sigma_m = E_m \varepsilon_m, \sigma_f = E_f \varepsilon_f \quad (5,6,7)$$

where E_C – elastic modulus of composite;
E_m – elastic modulus of matrix;
E_f – elastic modulus of fibre.

If the fibers extended to the full length of the composite, then the area ratio will be the same as the volume ratio.

$$E_C = E_f V_f + E_m V_m \quad (8)$$

The above equation (8) is the rule of mixture and could be used to compute the elastic modulus of composite materials.

Table 4

Mechanical characteristics of PAN nanofiber mat with epoxy specimens

Type of collector	Maximum force applied, N	Tensile strength, MPa	Elastic modulus of composite, GPa	Elastic modulus of fibre, GPa
Stationary	313.7	21.75	4.92	6.09
Sliding	345.11	24.88	6.47	9.19

Analysis

Polyacrylonitrile (PAN) nanofiber composite is utilized to strengthen the side panel instead of the frequently used *Acrylonitrile Butadiene Styrene* (ABS) plastic. The mechanical properties of ABS plastic are presented in Table 5. The side panel was designed in Solid Works and then imported into ANSYS for simulation. Figure 2 shows the automated mesh of the ABS plastic side panel. The higher the mesh quality, the better the chances of getting more precise outcomes. As shown in Figure 3, initial boundary conditions are a force of 3000 N distributed on the whole body (Figure 3 -red surface) applied to the whole body of the side panel in the normal to the body plane direction and fixed from all nodes of the top and bottom edge.

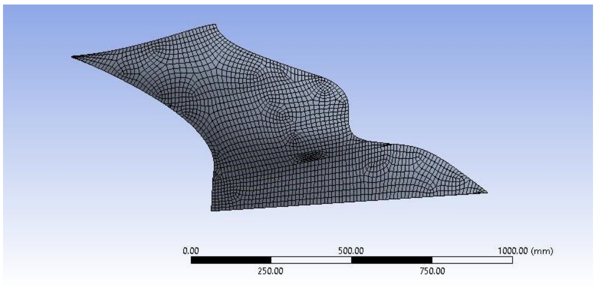

Fig. 2. **Meshing of side panel**

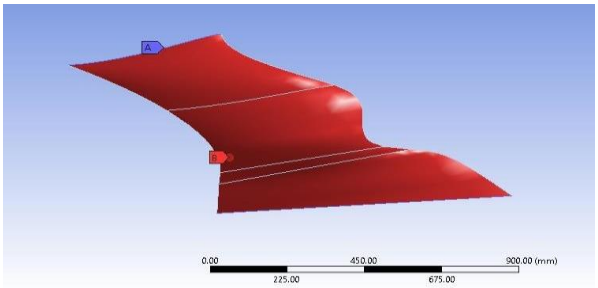

Fig. 3. **Boundary condition of side panel**

Table 5

Mechanical properties of *Acrylonitrile Butadiene Styrene* plastic

Properties	Values
Young's modulus	2390 MPa
Poisson's ratio	0.399
Tensile ultimate strength	44.3 MPa
Tensile yield strength	41.4 MPa

According to the ANSYS data library, ABS plastic has an elastic modulus of 2340 MPa. After the static analysis, it was determined that the maximum equivalent (Von misses) stress is 43.888 MPa, the maximum equivalent elastic strain is 0.0183, from Figure 4 and Figure 5, respectively. The obtained total deformation of the ABS plastic side panel is 42.40 mm, shown in Figure 6.

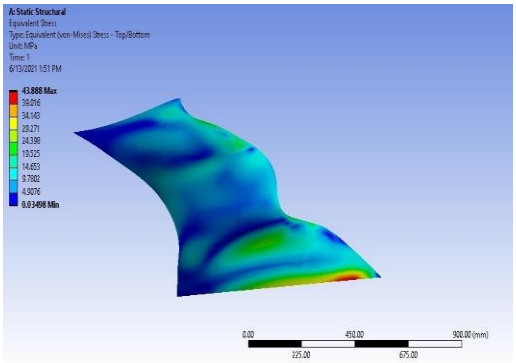

Fig. 4. **Equivalent stress of ABS plastic side panel**

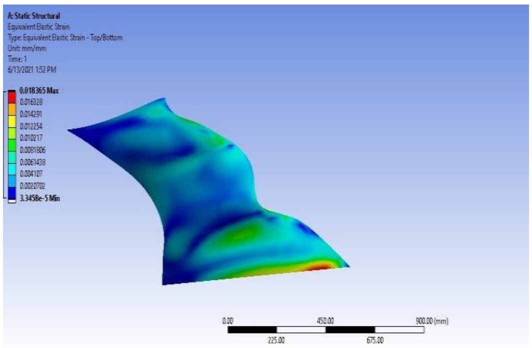

Fig. 5. **Equivalent strain of ABS plastic side panel**

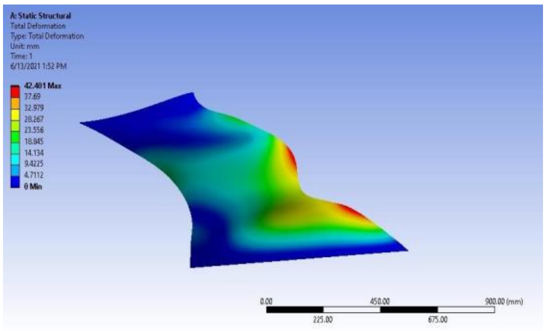

Fig. 6. **Total deformation of ABS plastic side panel**

The ACP (Ansys Composite Pre-Post) tool can examine the side panel of the fibre mat layer by a layer with PAN nanofiber composite. A side panel with 11 layers was built to examine the behaviour of each layer of the panel, resulting in a better understanding of the body. Each layer is 0.2 mm thick, resulting in a total thickness of 2.2 mm. Epoxy is used for the first and last layers. Six epoxy layers and five PAN nanofiber layers overall. After each layer has been added by the appropriate material, as illustrated in Figure 3, 3000 N force was also applied to the entire body of the side panel in the direction of normal to the body.

After each layer has been added using the appropriate material, which is the PAN nanofiber mat and epoxy as the matrix, the boundary conditions identical to those used in the ABS plastic side panel (see Figure 3) have been added. Similarly, 3000 N force was then applied to the body of the side panel in a normal direction. The equivalent (Von misses) stress is 100.59 MPa (figure 7), the equivalent elastic strain is 0.0141 (figure 8), and the total deformation is 51.049 mm (Figure 9).

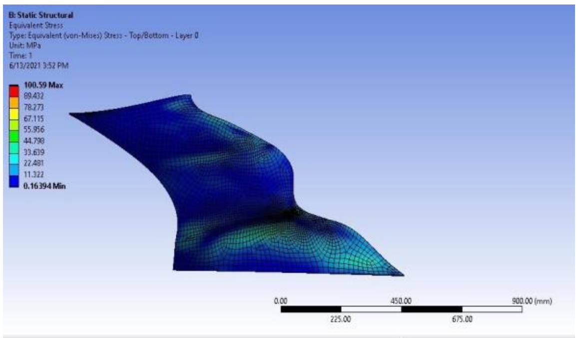

Fig. 7. **Equivalent stress of PAN nanofiber composite**

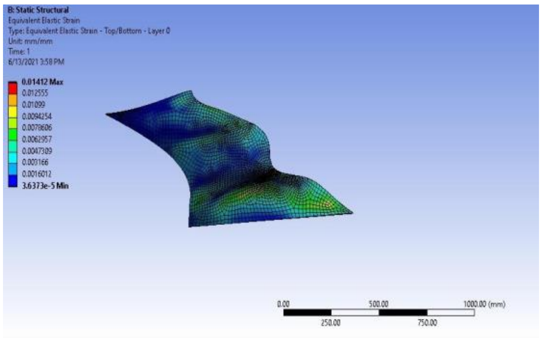

Fig. 8. **Equivalent elastic strain of PAN nanofiber composite**

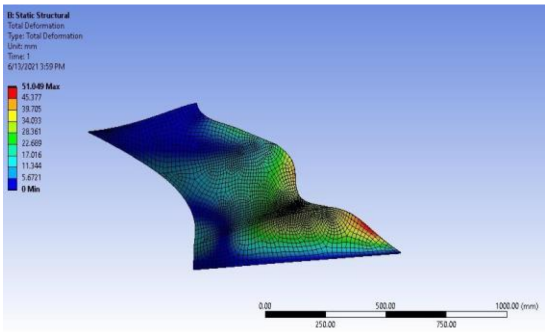

Fig. 9. **Total deformation of PAN nanofiber composite**

Results

To understand the behaviour of each layer of the side panel, it has been undergone for the static study analysis. All maximum and minimum stresses of each layer of the PAN nanofiber composite side panel are presented in Figures 10 to 19. From the static analysis of the 11 layers of the PAN nanofiber composite side panel, it has been observed that the maximum stress results in the first layer and last layer, which are made of epoxy are 36.43 MPa and 29.18 MPa, respectively, Figures 10 and 19. Figure 10 illustrates the central layer of the side panel which is obtained with the maximum stress of 29.71 MPa.

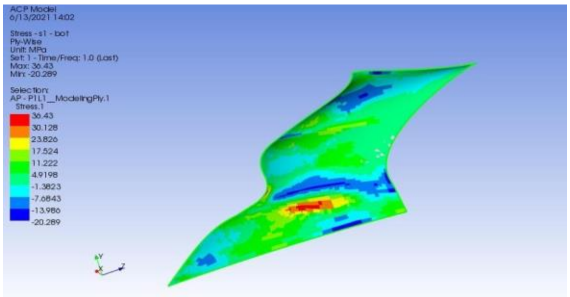

Fig. 10. **Maximum stress on the 1st layer, P1**

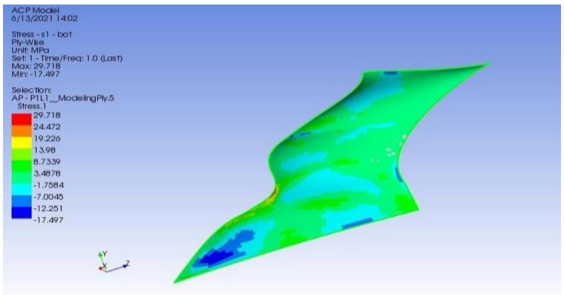

Fig. 11. **Maximum stress on the central layer, P5**

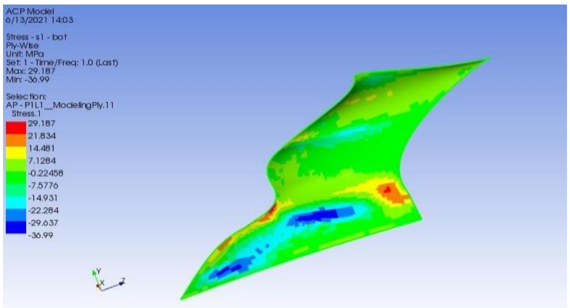

Fig. 12. **Maximum stress on the last layer, P11**

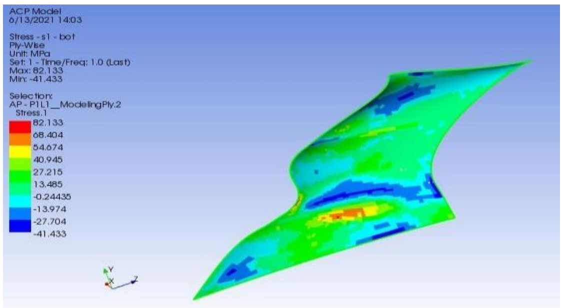

Fig. 13. **Maximum stress on the 2nd layer, P2**

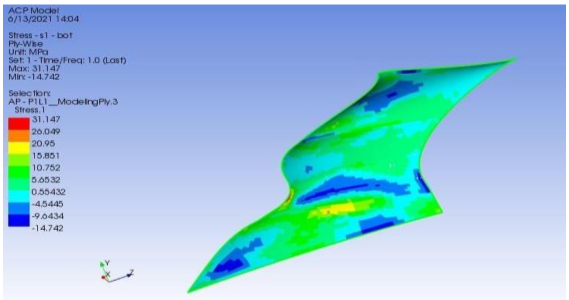

Fig. 14. **Maximum stress on the 3rd layer, P3**

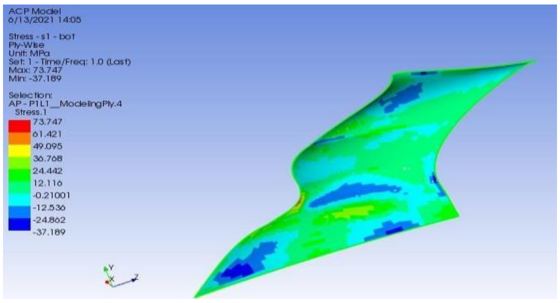

Fig. 15. **Maximum stress on the 4th layer, P4**

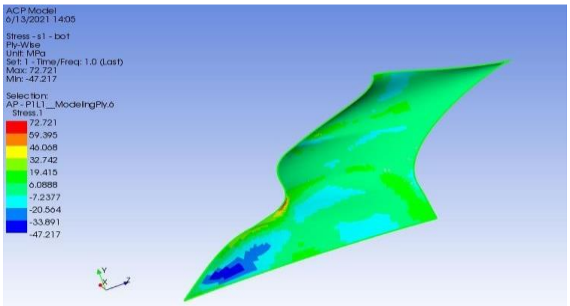

Fig. 16. **Maximum stress on the 6th layer, P6**

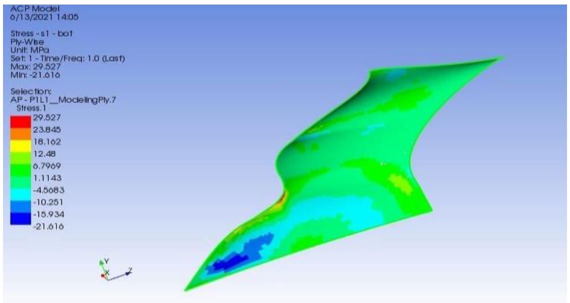

Fig. 17. **Maximum stress on the 7th layer, P7**

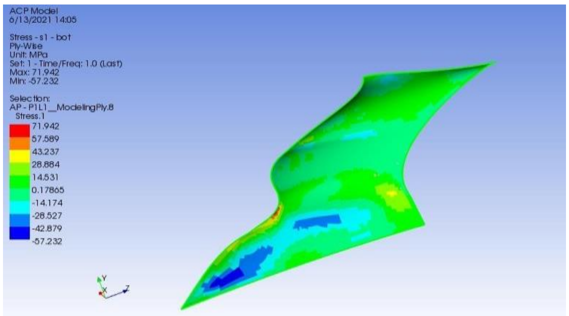

Fig. 18. **Maximum stress on the 8th layer, P8**

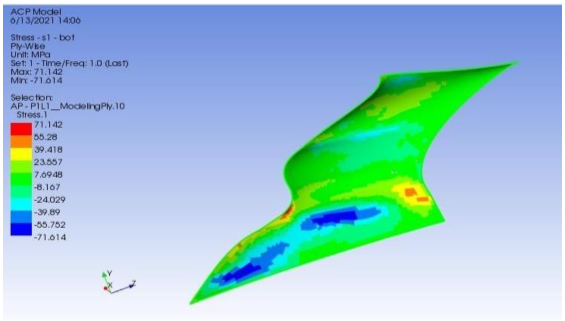

Fig. 19. **Maximum stress on the 10th layer, P10**

The force was applied to the first layer of the composite structure, and it was noticed that the highest stress occurred in that layer and progressively decreased until it reached the last layer, as shown in Figures 10 to 19, each layer represents the maximum stress (red marks) at a different place. The position of the maximum stress varied between the layers. According to the side panel analysis, the PAN nanofiber mat with epoxy composite offers more superior mechanical properties than ABS plastic and has the potential to replace ABS plastic. The computed outcomes are compared and tabulated below in Table 6.

Table 6

Comparison of the mechanical properties of ABS plastic and PAN nanofiber composite

Property	ABS plastic	PAN nanofiber composite
Yield strength, MPa	41.4	144.05
Equivalent Stress, MPa	43.88	100.59
Equivalent Strain	0.018	0.014
Thickness, mm	3	2.2
Total deformation, mm	42.014	51.041

Conclusions

1. The first part of the research involves measuring the strength of the PAN nanofiber mat created by electrospinning polyacrylonitrile solution. On both fixed and movable substrates, electrospinning

was carried out linearly. The findings indicate that nanofibers in the moving substrates are strongly aligned and exhibit an improvement in the mechanical characteristics of 14.3%.

2. According to the findings of the tensile strength test, the tensile strength of polyacrylonitrile epoxy specimens in sliding substrates (24.88 MPa) is 12.58% more than that in stationary substrates (21.75 MPa). According to the numerical analysis, the elastic modulus of the composite of polyacrylonitrile epoxy specimens in stationary substrates is 24.26% greater than the elastic modulus of the composite of polyacrylonitrile epoxy specimens in stationary substrates, and the elastic modulus of the composite of polyacrylonitrile epoxy specimens in sliding substrates it is 33.73% greater than the elastic modulus of the composite of polyacrylonitrile epoxy specimens in stationary substrates.
3. In the second section of the investigation, ANSYS was utilized to examine the mechanical characteristics of PAN nanofiber membranes and ABS plastic used in automotive side panels. The yield strength, equivalent stress, and total deformation of the PAN nanofiber composite surpass those of the ABC plastic by 71.25%, 56.37%, and 17.68%, respectively, when the composite is only 2.2 mm thick, compared to 3 mm for ABS.
4. The force was applied to the first layer of the composite structure, and it was noticed that the highest stress occurred in that layer and progressively decreased until it reached the last layer. The position of the maximum stress varied between the layers.

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Author contributions

Conceptualization, J.V.S., and J. K..; methodology, J.V.S. and A.S.; software, J.V.S. and A.S.; validation, J.V.S.; formal analysis, J.V.S. and A.S.; investigation, J.V.S. and A.S.; data curation, S.P.K. and J.V.S.; writing – original draft preparation, J.V.S. and S.P.K.; writing – review and editing, J.V.S.; visualization, J.V.S.; project administration, S.P.K. and J.V.S; funding acquisition, J.V.S. and S.P.K. All authors have read and agreed to the published version of the manuscript.

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