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A STUDY ON THE MECHANICAL, OPTICAL AND ELECTRICAL PROPERTIES OF NYLON-MESH/EPOXY COMPOSITE

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ABSTRACT

We fabricated the nylon-mesh reinforced epoxy composite by using the hand lay-up method. In this composite, nylon mesh act as the reinforcing material whereas epoxy resin is the matrix material. Comparisons have been made between blank epoxy sheet and the composite. We observed improved mechanical properties such as tensile strength, strain, hardness, and flexural strength from the composited rather than blank epoxy sheet. However, Young's modulus was not found promising. In case of optical observations, Light absorbance increases, and optical band gap decreases slightly. Considering the Electrical properties, we observed better electrical insulation properties from our fabricated composite than the blank epoxy sheet. In addition, the water absorption properties have also been discussed in this research article. These observations of different properties will contribute to open the new wings of many new applications and help to further improve the quality of the composites.

Keywords: *Composite, Hand Lay-up, Light Absorption, Water Absorption*

1. INTRODUCTION

Composites are made up of two or more constituents that exhibit different mechanical, optical and electrical properties which is far different compared to an individual component. At the solid solutions or mixtures, it contains separate and distinct individual component, but composites are different from them. Each component plays significant role to improve the desired properties and performance of the final product. Metal, ceramic, and polymer may act as matrices. Nowadays, polymer matrix composites (PMC) are used in sophisticated field such as robots, defense, aerospace, and automobile sectors [1]. Some applications of PMCs in automotive industries are driveshaft, racing car bodies, leaf springs, bumpers, doors, body panels, and so on. They are also used in sports goods, marine, biomedical, electrical, structural and many other purposes. The PMCs exhibit vast applications due to having some extraordinary properties e.g., light weight, high stiffness, high strength and good abrasion and chemical resistance. Two most important types of polymer matrix composites are Graphite Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP) [2]. But these composites are expensive. In order to cut down the cost of raw materials and manufacturing processes, our aims were to develop nylon-mesh reinforced epoxy composite due to having a large combination of different properties.

Mechanical properties such as compression, flexural, tensile and impact strength from sisal-glass fiber reinforced composite materials have been observed by Alagarraja et al. [3]. They found that improved mechanical properties were obtained from hybrid composite prepared by adding sisal into the glass fiber. The effect of multiple delamitation's on the tensile, flexural and compressive strength of e-glass/ epoxy composites have been investigated by Aslan et al. [4]. Based on the primary critical buckling and re-buckling loads delamination effects have been evaluated. The results explore that critical buckling load, flexural and compressive strength was significantly influenced by the presence of large multiple delamination. H. Bisaria et al. [5] observed the mechanical properties e.g., tensile, impact and flexural strength from the blank epoxy and epoxy act as matrix with short jute fiber reinforced composites. For 15 mm length of fiber maximum flexural and tensile strength were evaluated. However, the maximum impact strength was evaluated for 20 mm length of fiber. Naresh et al. [6] investigated the tensile strength influenced by strain rate from the carbon/epoxy, glass/epoxy and hybrid (glasscarbon/epoxy) composites. The mechanical properties of nylon/epoxy composite have been investigated by Meshram et al. [7]. They found higher thrust force and tensile strength compared to the pure epoxy polymer. S. Sharma et al. have been studied the electrical and thermomechanical characteristics of laminar composites made up of reinforced multi-walled carbon nanotubes (MWCNTs) bucky paper with epoxy matrix [8]. They observed that the electrical conductivity was reduced after incorporating bulky paper as reinforcement in epoxy matrix. However, the incorporation of 0.05 wt% of MWCNT could improve the electrical conductivity. The glass transition temperature (Tg) was also improved compared to the pure epoxy [8]. Improved flexural properties were found from clay/epoxy nanocomposites studied by Bozkurt et al. [9]. Similar results were also observed from carbon nanofiber filled carbon/epoxy laminated composite [10]. Chowdhury et al. [11] investigated the huge enhancement of flexural strength from woven carbon fiber reinforced polymer matrix composite with 2 wt% nanoclay particles on it. Dorigato et al. [12] also studied the mechanical properties on the carbon fiber reinforced materials in which the epoxy-clay act as a matrix material. They found improved mechanical properties along with the dispersion degree of clay nanoparticles in the composite.

Above literature reveals that the composites were developed with many different matrices and reinforced materials having various useful applications and many different properties, although the study on the properties were not sufficient to explore the usefulness and feasibility of many different types of fabricated composites. In contrast, fabrication processes are not always cost effective and having health hazardous issues. Considering these points, in this research, we fabricated the nylon-mesh/epoxy composite by using low cost fabrication technique hand lay-up method and having no health hazardous issues. Another important point is that very limited studies were observed on the different properties such as mechanical properties, electrical and optical properties of nylon-mesh/epoxy composite [13-15]. In sort, to maximize its application in daily life and replace the expensive composites we wanted to optimize the properties of this composite. In this work, mechanical properties including tensile strength, Young's modulus, flexural strength, elongation and hardness were investigated. Optical properties such as absorption of light and optical band gap have been observed. I-V characteristics have also been studied for understanding the electrical properties of the fabricated composite material.

2. MATERIALS AND METHODS

2.1 Materials and fabrication of nylon-mesh/epoxy composite

We used epoxy resin ($C_{21}H_{25}ClO_5$) in this experiment has been supplied by Lucky Acrylic and Fiber (Bangladesh) having purity above 98% and melting point of 210^o C, whereas nylon-mesh has been collected from ordinary packing bags. The chemical structures of epoxy resin and nylon are given below indicating the epoxide, carbonyl and amide groups [16,17].

To fabricate the nylon-mesh/epoxy composite, epoxy resin and hardener (DETA) was measured at the ration of 10:1. The ratio of resin to hardener is very important. Sufficient amount of crosslinking formation between the hardener and epoxy resin may provide required hardness to epoxy resin. We found prominent hardness and performance of epoxy resin while using 10:1 ratio rather than other ratios such as 1:1, 5:1, 8:1. They were mixed thoroughly. Then half of the resin was poured on the glass mold. After that, the previously sized nylon mesh fiber was placed on to the mold over the epoxy resin. Then rest of the resin was poured over the fiber. It takes around 24 hours to complete the mixture properly and turn into composite. This planar composite sample had an approximate thickness of 2 mm. The diagram of fabricated nylon-mesh/epoxy composite is shown in Fig. 1.

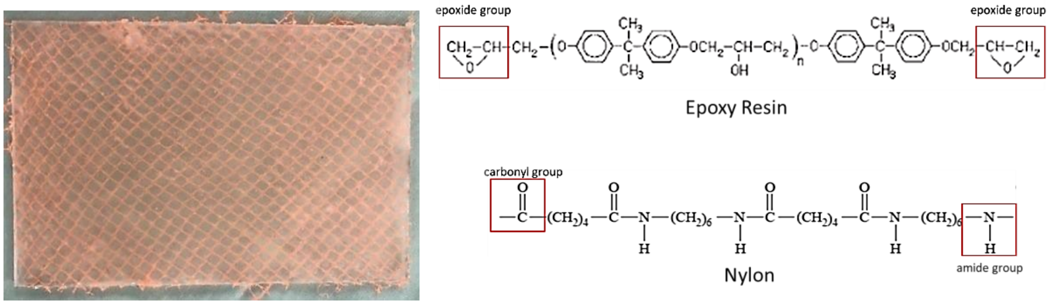


Fig.1. Fabricated Nylon-mesh/Epoxy Composite

2.2 Measurement Techniques of Different Types of Properties

Tensile strength of the composites was evaluated by using Universal Testing Machine (Hounsfield Co. Ltd., UK, model H50KS). Parameters were set to measure the tensile properties by UTM. Parameters were extension range = 100 mm, gauge length = 25 mm, speed = 2 mm/min, approach speed = 2 mm/min, pre-load = 0. Tensile strength and Young's modulus were determined using this UTM machine. Flexural strength of the films was measured also by UTM machine. To measure the flexural strength, the specimens were designed in 6cm length and 1cm in width with around 2 mm thickness. The test was repeated 3 times for each material for obtaining the average value and to avoid errors. The strain value was also measured from this test. Hardness of the composite was investigated by using Leeb H-1000 Portable Hardness Tester. Hardness test was repeated 20 times for each sample for obtaining the average value to avoid errors during the hardness measurement. For optical properties measurement, light absorption and optical band gap properties were studied using UV Spectrophotometer - UV-1601 Spectrometer [13]. For the measurement of electrical properties, I-V characteristics of the fabricated composites were studied using a Keithley 6514/E Bench Digital Multimeter. To measure the water absorption rate of the samples, after their emersion in water they were weighted in a Mettle balance. For this test, the specimens were designed in 3cm length and 1cm in width. To ensure the fact that whether the samples absorb water or not this test was done.

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties

Fig. 2 shows the comparative mechanical properties of blank epoxy and nylon-mesh/epoxy composite. The observed tensile strength of epoxy/nylon-mesh was 47.1 MPa, which is 49.5% more than the blank epoxy polymer. Fibers used in this experiment are long continuous fibers of nylon-

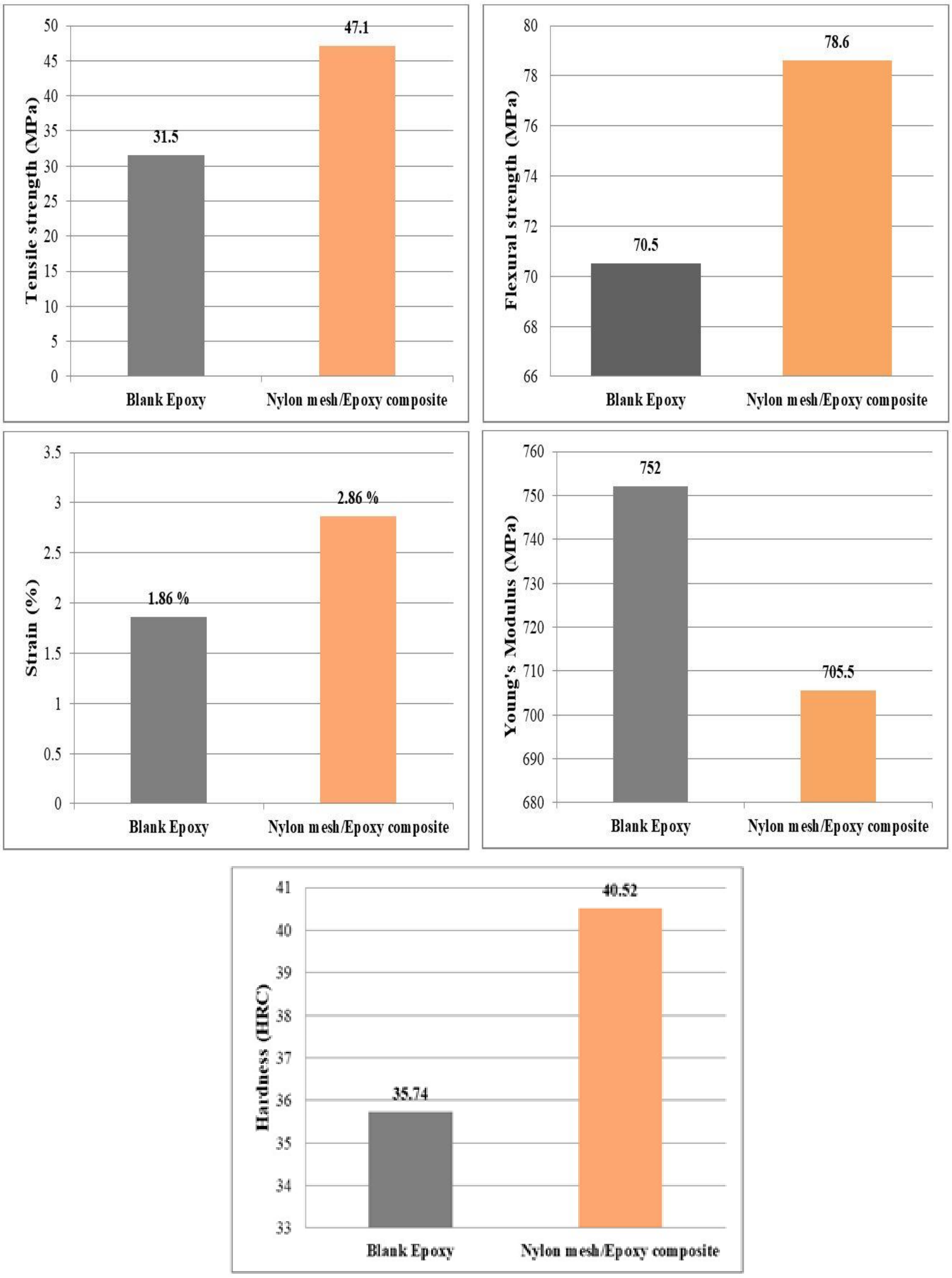
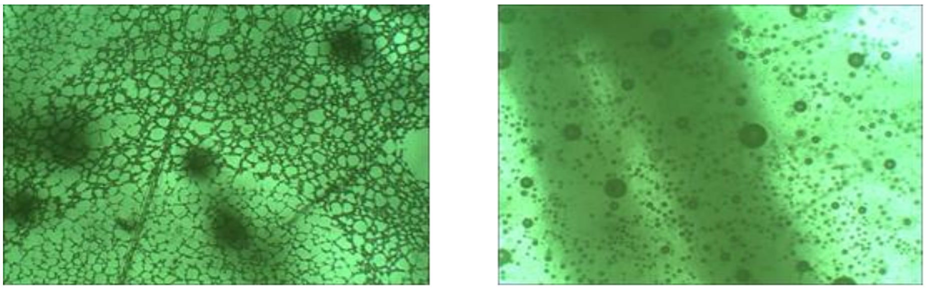


Fig. 2: Comparison of mechanical properties such as tensile strength, flexural strength, strain, young's modulus, and hardness between blank epoxy and nylon-mesh/epoxy composite.



(a) (b)

Fig. 3: Optical Microscopic View of (a) Blank epoxy (b) Nylon-mesh/Epoxy composite.

mesh. Using shorter fiber lengths were avoided in order to avoid damage creation of the composites. Shorter fiber lengths may create stress concentration sites and sometimes failure occurs. But with the longer fibers and less fiber ends, the probability of crack formation reduces. This possibly clarifies the increase of tensile strength [18]. Due to incorporation of the fibers, the void reduces inside the composite which is confirmed by the optical microscopic view from the blank epoxy (Fig. 3(a)) and nylon-mesh/epoxy composite (Fig. 3(b)). This results higher flexural strength from the nylon-mesh/epoxy composite compared to the blank epoxy. Epoxy has a moderate elastic modulus. But a problem with nylon is its low modulus. The Young's modulus of the composite was decreased noticeably compared to the blank epoxy. Highly cross-linked network structure may occur between blank epoxy and hardener that results high modulus structure. In case of nylon-mesh impregnated epoxy composite the highly stiff cross-linked network between the epoxy and multifunctional hardener somehow interrupted due to the formation of relatively softer bridging network among the epoxy-nylon-hardener of the Nylon-mesh/Epoxy composite. The relatively weaker bridging network of nylon-mesh with epoxy through the hydrogen bonding develops a soft interface between the upper and lower layers of the epoxy beds. So, the Young's modulus of the Nylon-mesh/Epoxy composite decreases rather than increases compared to that of blank epoxy composite. The overall effect of the addition of nylon-mesh slightly enhanced the hardness of the nylon-mesh/epoxy composites.

3.2 Optical Properties

3.2.1 Light Absorbance

The main purpose of UV light absorption is to cure the epoxy-based composite. The curing process helps to improve the mechanical properties of the epoxy-based composites. Result shows a higher absorption of UV light than the blank epoxy sheet. Carbonyl groups and non-pair electron of the amide groups of the polyamide linkage of nylon cause the absorption of the light, resulting in higher light absorption of the epoxy/nylon-mesh composite compared to that of blank epoxy sheet. The nylon-mesh absorbs some amount of light, increasing the overall absorbance of the composite as shown in Fig. 4.

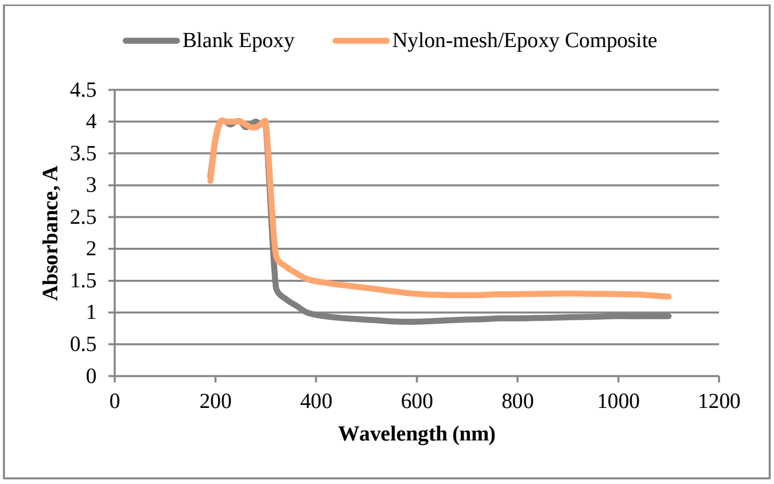
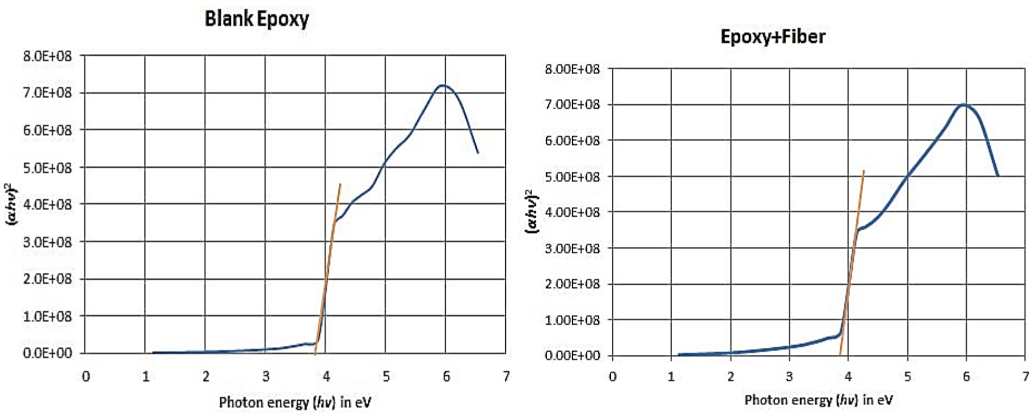


Fig. 4: Absorbance vs wavelength curve for blank epoxy and nylon-mesh/epoxy composite.

3.2.2 Optical Band Gap Energy

From Fig.5, the values of optical band gap energy of epoxy polymer and nylon-mesh/epoxy composite are being tabulated at Table 1. A Tauc plot is used to determine the optical bandgap, or Tauc bandgap, of either disordered or amorphous materials. In this process, the slope of the straight line in the gap has to be measured in order to get the optical bandgap. We choose the energy range following the Tauc plotting method. The optical bandgap is the threshold for photons to be absorbed. According to the results, the optical band gap values are very close between blank epoxy and nylon-mesh/epoxy composite and this is due to the amount of reinforcement used in composite. However, the slight reduction of band gap of nylon-mesh epoxy composite is due to the shift of absorption spectra to higher wavelength. So, the composite reveals better electrical conductivity compared to blank epoxy.



(a) (b)

Fig. 5: Graph for optical band gap energy of (a) Blank epoxy (b) Nylon-mesh/epoxy

Table 1: Optical band gap energy of the fabricated composite.

Sample	Bandgap energy (eV)	Decrease (%)
Blank epoxy	3.8	-
Nylon-mesh/epoxy	3.7	2.63

3.3 Electrical Property: I-V Characteristics

The effect of reinforcing epoxy with nylon mesh fiber on its I-V characteristics has been observed that is shown in Fig.6. It is evident that the epoxy becomes absolutely insulator within the range of 0 to 100 volts. Epoxy is generally insulating in nature. But according to the graph, it suddenly starts to conduct a little amount of electricity (in μA scale) after applying more than 60 volts. Dielectric breakdown of epoxide rings might cause this conductivity. Polyamide shows better electrical insulator at dry conditional though it exhibits hygroscopic nature. Electrical resistance of some materials may change by the absorption of water. Nylon act as a very good insulator rather than wool or cotton due to its less water absorbance nature. Incorporation of nylon in epoxy breaks the epoxide continuity and reduces the electrical conductivity.

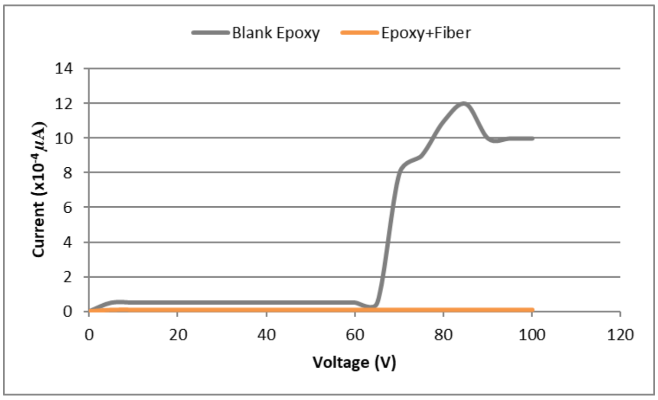


Fig. 6: Effect of nylon-mesh reinforcement on I-V characteristics of epoxy polymer.

3.4 Water Absorption

It is observable from Fig.7, that epoxy has a very poor, only 1.8%. But after reinforcing the polymer with nylon-mesh fiber, the water absorption increases significantly, to 12.94%.

The characteristics of nylon significantly changes with the moisture absorbance from the air. Moisture plays an important role on the mechanical properties. It may reduce the strength and stiffness, whereas increase the elongation and toughness properties. In general, the impact strength and other energies of the material could be increased with the increase of moisture. Nylons attract moisture due to have polar structure. Temperature, exposure time, relative humidity, thickness of the nylon part, all these parameters are related with the amount of moisture absorbance. Indeed, nylon part can absorb a little amount of moisture due to have higher crystallinity compared to the less crystalline molded part. All these facts make the nylon-mesh reinforced epoxy composite absorb more water than the blank one.

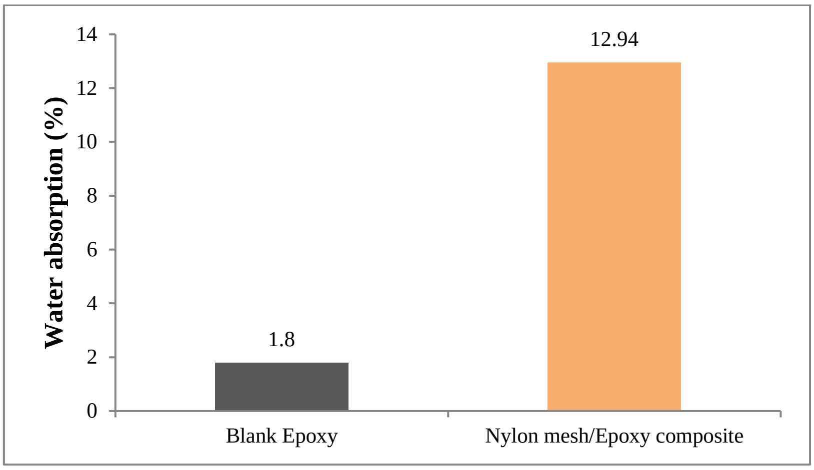


Fig. 7: Water absorption variation of epoxy and nylon-mesh/epoxy composite.

4. CONCLUSIONS

Nylon-mesh reinforced epoxy composite has been made successfully in the laboratory by using hand lay-up method. Incorporation of nylon-mesh into epoxy matrix improved the mechanical properties. However, Young's modulus showed significant decrease. Remarkable fall of electrical conductivity for the composite was found after a certain applied voltage. So, it became a very good insulator compared to the pure epoxy. In case of optical properties, there was no mentionable variance between the composite and pure epoxy. Increase in water absorption was also observed according to the experimental results. With the advancement of time, the demand of polymer composites is increasing for versatile applications. Nylon-mesh/epoxy composites are widely used in automotive, aerospace, defense, robots, construction, oil and gas industries, and marine industries due to its low cost and outstanding properties. However, the material gap still exists. This study is hoped to be helpful to fulfill that gap partially.

REFERENCES

[1] A. Nayak and S. K. Pradhan, Design of a new in-pipe inspection robot, Procedia Engineering. **97**, 2081–2091, 2014.

[2] D. Nguyen, M. S. Bin Abdullah, R. Khawarizmi, D. Kim and P. Kwon, The effect of fiber orientation on tool wear in edge-trimming of carbon fiber reinforced plastics (CFRP) laminates, Journal of Wear, **450–451**, 203213, 2020.

[3] K. Alagarraja, A. Dhamodharan, K. Gopinathan, R. M. Raj and K. R. Kumar, Fabrication and Testing of Fiber Reinforced Polymer Composites Material, Journal of Mechanical and Civil Engineering (IOSR-JMCE) **3**, 27–34, 2014.

[4] Z. Aslan and F. Daricik, Effects of multiple delaminations on the compressive, tensile, flexural, and buckling behavior of E-glass / epoxy composites, Composites Part B: Engineering, **100**, 186–196, 2016.

[5] H. Bisaria, M. K. Gupta, P. Shandilya, R. K. Srivastava, Effect of Fibre Length on Mechanical Properties of Randomly Oriented Short Jute Fibre Reinforced Epoxy Composite, Materialstoday: Proceedings, **2**, 1193-1199, 2015.

[6] K. Naresh, K. Shankar, B. S. Rao and R. Velmurugan, Effect of high strain rate on glass/carbon/hybrid fiber reinforced epoxy laminated composites, Composites Part B: Engineering, **100**, 125–135, 2016.

[7] P. Meshram, S. Sahu, M. Z. Ansari and S. Mukherjee, Study on mechanical properties of epoxy and nylon/epoxy composite, Materials Today: Proceedings, **5**, 5925–5932, 2018.

[8] S. Sharma, B. P. Singh, S. S. Chauhan, J. Jyoti, A. K. Arya, S. R. Dhakate, V. Kumar and T. Yokozeki, Enhanced Thermomechanical and Electrical Properties of Multiwalled Carbon Nanotube Paper Reinforced Epoxy Laminar Composites, Composites Part A: Applied Science and Manufacturing, **104**, 129-138, 2018.

[9] E. Bozkurt, E. Kaya and M. Tanoglu, Mechanical and thermal behavior of non-crimp glass fiber reinforced layered clay/epoxy nanocomposites, Composites Science and Technology, **67**, 3394-3403, 2007.

[10] Y. Zhou, F. Pervin, V. K. Rangari and S. Jeelani, Fabrication and evaluation of carbon nano fiber filled carbon/epoxy composite, Materials Science and Engineering A, **426**, 221-228, 2006.

[11] F. H. Chowdhury, M. V. Hosur and S. Jeelani, Studies on the flexural and thermomechanical properties of woven carbon/nanoclay-epoxy laminates, Materials Science and Engineering A, **421**, 298-306, 2006.

[12] A. Dorigato, A. Pegoretti and M. Quaresimin, Thermo-mechanical characterization of epoxy/clay nanocomposites as matrices for carbon/nanoclay/epoxy laminates, Materials Science and Engineering A, **528**, 6324-6333, 2011.

[13] M. T. Rahman, Md. Asadul Hoque, G. T. Rahman, M. A. Gafur, Ruhul A. Khan and M. Khalid Hossain, Study on the mechanical, electrical and optical properties of metal-oxide nanoparticles dispersed unsaturated polyester resin nanocomposites, Results in Physics **13**, 102264, 2019.

[14] A. Badawi, Characterization of the optical and mechanical properties of CdSe QDs/ PMMA nanocomposite films, J Mater Sci Mater Electron, **26**, 3450–7, 2015.

[15] J. Al-Osaimi, N. Al-Hosiny, S. Abdallah, A. Badawi, Characterization of optical, thermal and electrical properties of SWCNTs/PMMA nanocomposite films, Iran Polym J, **23**, 437–43, 2014.

[16] K. S. Huang, Y. H. Nien, J. S. Chen, T. R. Shieh and J. W. Chen, Synthesis and Properties of Epoxy/TiO_2 Composite Materials, Polymer Composites, **27**, 195–200, 2006.

[17] P. K. Vagholkar, Nylon (Chemistry, Properties and Uses), International Journal of Scientific Research, **5**, 349-351, 2016.

[18] Y. Z. Phua, Z. A. Mohd Ishak and R. Senawi, Injection Molded Short Glass and Carbon Fibers Reinforced Polycarbonate Hybrid Composites: Effects of Fiber Loading, Journal of Reinforced Plastics and Composites, **29**, 2592-2603, 2010.