



Mechanical Properties of Nanocomposites Reinforced by Polyamide 66 Nanofibers

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Abstract

Mechanical properties of the polyamide 66 nanofibers / epoxy nanocomposite, involved (tensile strength, impact strength, and hardness) were tested. Four samples of nanocomposites were prepared involved (pure epoxy, epoxy with pure polyamide nanofibers, epoxy with (nanofibers + 0.02 wt.% Alumina nanoparticles), and epoxy with (nanofibers + 0.03 wt.% Alumina nanoparticles). Nanofibers of nylon66 prepared by electrospinning technique by dissolve (3g) of nylon66 in (17 ml) of formic acid. Nanofiber mixed with epoxy resin by (0.03) wt%. Results show there are an enhancement of mechanical properties of nanofibers nanocomposites, which prepared especially impact strength. On the other hand, the addition of alumina nanoparticles leads to more enhancement of impact strength of nanocomposites.

Keywords: Mechanical properties, Nanofiber, Nylon 66, Electrospinning, Nanocomposite, and aluminum oxide.

1. Introduction

Nanocomposites are composites in which at least one of the phases illustrate dimensions in the nanometer field [1 nm = 10.9m]. As in the state of microcomposites, nanocomposite materials can be divided, according to their matrix materials, in three various kinds Ceramic Matrix Nanocomposites (CMNC) Metal Matrix Nanocomposites (MMNC) Polymer Matrix Nanocomposites (PMNC) [1].

Nanofiber materials have different properties such as flexibility in surface functionalities, excellent stiffness and tensile strength in comparison with other materials due to the large surface area to volume ratio that makes them take place in many applications: sound absorption materials, protective clothing. Also in the electrical and visual application, drug transmission, tissue engineering, turned dressing, drug performance, and filtration. Many processes used to produce the nanofibers of polymer, for example, template synthesis, drawing, self-assembly, phase separation, and electrospinning. Electrospinning is the most interest technique in the present because it is simple, efficient useful, low-cost and versatility in spinning a large range of polymer nanofibers with its feasible application in electronic devices, nanocomposites, and membranes]. Polymer nanofibers fabricated by electrospinning process within accelerating a charged polymer jet in an electrical field. The output nanofibers have diameters from 10 to 100 μm [2].

Nylon-66 is a semi-crystalline material that has a collection of strength, flexibility toughness, and abrasion resistance. It is also recognized for its dye-ability, low coefficient of friction, low creep, and resistance to solvents, fuels, goals, molds, and body solutions. The applications of nylon-66 series from textile fibers, films, tapes, board packaging to electronics and automotive sectors [3].

Laminated composites have been extensively utilized in many body applications because of their high strength and stiffness at low weight and good corrosion-resistance and fatigue properties [4].

In many applications polyamides have been reinforced with mineral fillers like aluminum or calcium silicates or with glass and carbon fibers. Mineral fillers result in the increase of modulus and elasticity and tensile strength, decrease in elongation, while glass or carbon reinforced fibers result in improved impact strength. In reinforced or filled polyamides the issue is the efficiency of bonding agents and the aspect ratio that is the length to diameter ratio of the fiber in the final product. The applicability of polyamides in different applications has been enlarged with the emergence of nanocomposites. Improved properties in terms of strength, heat deflection temperature, dimensional stability, gas barrier, flame retardancy, and electrical conductivity can be listed as highlighting features of polyamide nanocomposites [5].

In 2015, Yahaya et al. [6] examined the mechanical properties of the kenaf- aramid fiber strengthened epoxy composite. Kevlar fiber epoxy resin shows higher flexural and tensile properties compared to kenaf fiber reinforced composite. Instead of impact properties, kenaf fiber reinforced composites are higher than Kevlar fiber reinforced composite. As the number of sheets is higher the mechanical properties are great.

In 2015, Simona [7] used four types of resins: T19-38/500, T19-38/700, L 50-54, A 19-00 and two types of reinforcing materials: Kevlar pulp and glass fiber to obtain special and physical-mechanical properties of the composites with short fiber reinforced epoxy resin matrix. From the results, it is observed that the composite reinforced with glass fibers have properties much better than those with Kevlar. The best mechanical properties (tensile strength, flexural strength, and resilience) has the composite with the T19-38/700 epiloxx resin matrix reinforced with a glass fiber.

In 2017, Bertan [8] improved the fracture toughness by using carbon fiber-epoxy composites with electrospun polyamide-6,6

(PA 66) nanofibers. These nanofibers are directly deposited onto carbon fabrics before composite manufacturing via vacuum infusion. Three-point bending, tensile, compression, interlaminar shear strength, and impact tests are complete on the reference and PA 66 interleaved specimens to value the control on PA 66 nanofibers on the mechanical properties of composites. It is observed that the electrospun PA 66 nanofibers are effective in improving toughness and impact resistance, compressive strength, flexural modulus, and strength of the composites. These nanofibers matter a decrease in the tensile strength of the composites. The glass-transition temperature (TGA) of the composites is impervious by the addition of PA 66 nanofibers. The aim of this project to manufacturing nanocomposite nanofibers material with high strength and high toughness for many applications such as shield and fenders in the military and civil application.

2. Experimental Procedure

2.1 Materials Used

Nylon 66 nanofiber with epoxy resin for this study were used as follows:

- 1- Nylon66 nanofibers prepared by electrospinning technique as a reinforcement material, by using nylon66 powder with weight colure and (114 g/cm^3) density dissolved in formic acid with (100.8°C) boiling point by 0.15 % consecration.
- 2- Epoxy resin type (Sicadure A LP*52)and (Sicadure B LP*52)were used as hardener as matrix material.
- 3- Nano-alumina (Al_2O_3) molecular weight 101.96 g/mol was used as reinforcement for nanofibers.

2.2 Nanofibers Preparation

2.2.1 Preparation of electrospinning solution

- 1- (3 g) of nylon 66 powder dissolved in (17 ml) of formic acid for obtaining on 15 % wt., then, were mixed by magnetic stirrer tools for 3 hr.then leave out for 1 hr. to remove all bubbles by vacuum.
- 2- Different ratios of nano alumina involve (2% and 3%)wt.% was added to the solution for preparing nanocomposite nanofibers.

2.2.2 Electrospinning set up

Preparing a typical system of electrospinning include holding the liquid in the medical syringe equipped with a metallic needle of thin diameter. This syringe to be connected to a syringe pump for the purpose of regulating the fluid pumping during the electrospinning process, usually to the positive electrode (anode) of HVPS connected to the metallic needle while the negative electrode (cathode) linked to the metal target which in turn linked to the ground.

In the horizontal electrospinning setup, the syringe pump is parallel to the floor and put is placed perpendicular to the collector on the ground. Because of the resulting electric field vector is parallel to the floor, while in the vertical setup of electrospinning, the collector put on the floor and put the syringe pump above the collector settling.

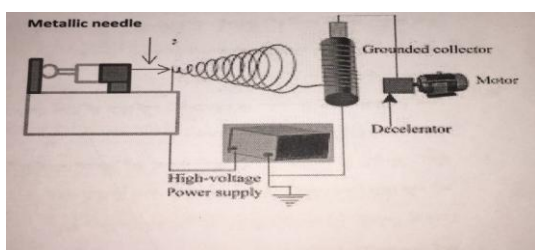


Fig. 1: Electrospinning set up with rotating cylinder collector

2.3 Nanocomposite Preparation

In this study nanocomposite prepared by using hand casting method and used glass mold. Mold has been prepared by using a sheet of $200 \times 150 \text{ mm}$ to make the composite. See figure 1.



Fig. 2: Glass mold.

2.3.1. Pure epoxy preparation

Fabrication of pure polymer based epoxy material prepared a mold of dimensions $200 \times 150 \times 3 \text{ mm}^3$. (7.5 ml) of Hardener was filled in a plastic container and mixed with rest amount(17.5) of epoxy resin. Hand stirring was done for approx. ten minutes to ensure the proper mixing. then, the mixture was put into the mold and left at room temperature for 24 hours to ensure the curing.



Fig. 3: Pure epoxy

2.3.2. Nylon66 nanofiber/ Epoxy resin nanocomposite preparation

A mold of the sheet is prepared of dimensions of $200 \times 150 \times 3 \text{ mm}^3$. The inner surface of the mold was wrapped with a cover in order to ensure the easy removal of the composite from the mold surface, so that good surface finish can be achieved. Reinforcement in the form of nylon66nanofiber mat was cut in the overall of the mold. Thermosetting polymer epoxy resin was mixed with hardener. Half of this mixture (epoxy and hardener) put in the mold. Then, put the sheet of nanofiber over this and set up the other half(epoxy and hardener) quickly. After deposition of thin layers, left it for the curing at room temperature for 24 hours.



Fig. 4: Nylon66 nanofiber/epoxy resin nanocomposite

2.4 Testes

2.4.1 Testes of nanofibers

Test of nanofiber involve “scanning electron microscopy” (SEM)

2.4.2 Testes of nanocomposite

Mechanical properties involve:

1- Tensile strength: the sample that has dimension 150*30 mm² and tested in this device.



Fig. 5: Tensile test

2- Impact strength: the sample that has dimension 55*10 mm² and tested in this device.



Fig. 6: Impact test

3- Hardness: the sample that has dimension 30*30 mm² and tested in this device.



Fig. 7: Hardness test

3. Results and Discussion

3.1 Nanofibers morphology

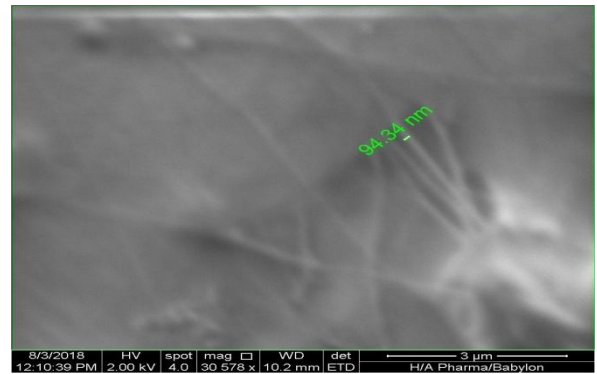
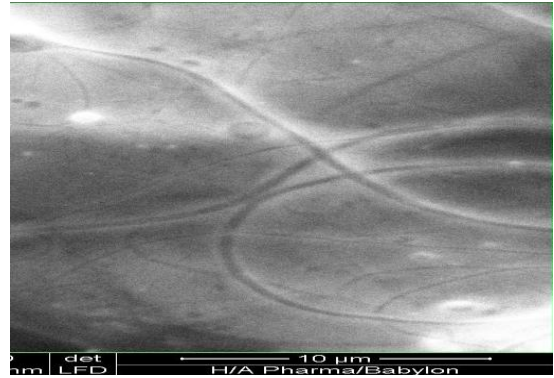


Fig. 3: a) Nylon66 nanofibers b) nylon 66 nanofiber textile

From fig 3. We note their area smooth nanofibers with 94.34 nm were obtained with only a few beads present in nanofibers morphology of textile because of there an unstable region through the pumping process.

3.2 Tensile Result

Table 1: Tensile strength of nanocomposite

Number Samples	Solution	Values of tensile strength
1	Pure epoxy	22
2	Epoxy with pure polyamide nanofiber	26
3	Epoxy with (nanofiber+0.02 wt.% Alumina nanoparticles)	22
4	Epoxy with (nanofiber+0.03 wt.% Alumina nanoparticles)	21

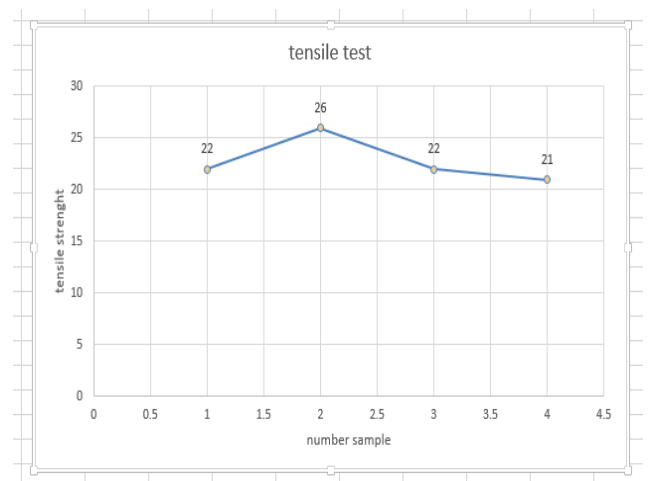


Fig. 4: Tensile strength of nanocomposite.

From figure(4) and table(1) notes tensile strength increase after added of nylon 66 nanofiber while it decreases with few degrees after adding of alumina nanoparticles and return to the original value of pure epoxy. This agreement with results [9].

3.2 Impact Result

Table 2. And fig 5. Show the impact strength of all samples:

Table 2: Impact strength of nanocomposite

Solution	Values of tensile strength
Pure epoxy	11.6
Epoxy with pure polyamide nanofiber	20
Epoxy with (nanofiber+0.02 wt.% Alumina nanoparticles)	21
Epoxy with (nanofiber+0.03 wt.% Alumina nanoparticles)	23.3

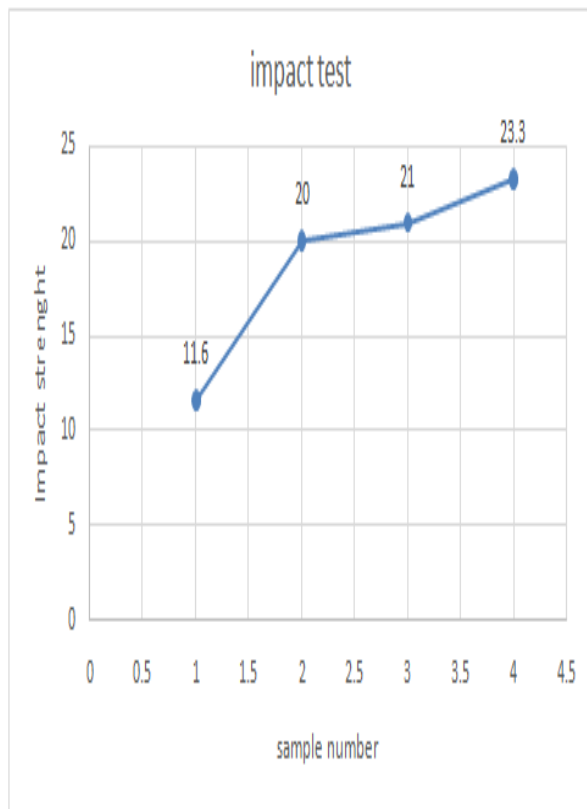


Fig. 5: The impact strength of nanocomposite.

From fig (5) and table(2), we note that increases of impact strength after adding nylon66 nanofibers and adding of nanocomposites nanofibers reinforced with alumina nanoparticles lead to more increasing of impact strength this is referred to increasing required energy failure of samples this is by nanomaterials effecting, which agreement with[10].

3.3 Hardness Result

Table 3. and fig 6. Show the hardness of all samples:

Table 3: Represent the values of nanocomposite materials for hardness test

Solution	Hardness
Pure epoxy	45.3
Epoxy with pure polyamide nanofiber	55
Epoxy with (nanofiber+0.02 wt.% Alumina nanoparticles)	65
Epoxy with (nanofiber+0.03 wt.% Alumina nanoparticles)	66

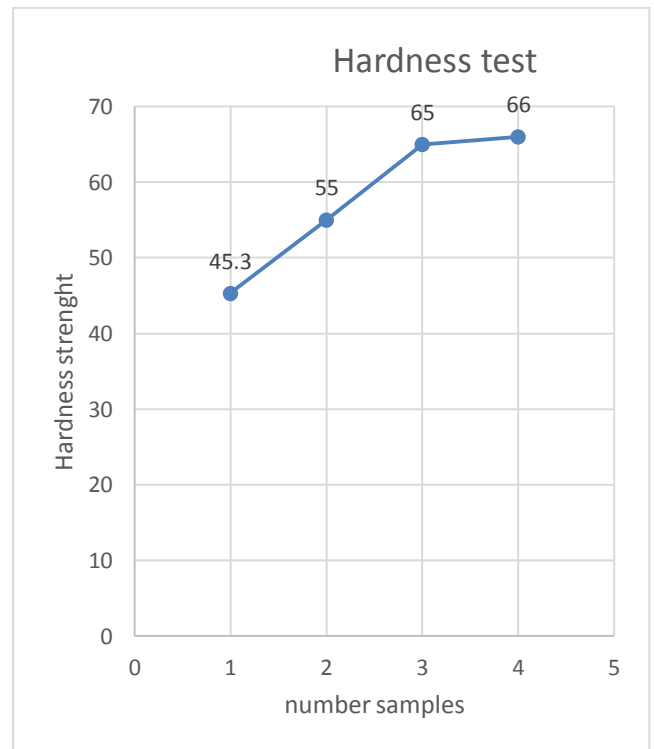


Fig. 6: Hardness of nanocomposite

From fig(6) and table (3) hardness increase after adding nanomaterials this is because the nanomaterials incorporated dramatically with matrix material this is lead to a strengthening of the nanocomposite. This agreement with results [11].

4. Conclusion

- 1- Electrospinning technique leads to produce nanofibers with 94.34 nm with smooth morphology.
- 2-Adding of nylon66 nanofibers lead to enhancement of the mechanical properties of the sample especially impact strength.
- 3-Adding of nylon66 nanofibers reinforcement alumina nanoparticles lead to more enhancement of impact strength and the optimum sample is (4 sample).

References

- [1] Camargo, P. H. C., Satyanarayana, K. G., & Wypych, F. (2009). "Nanocomposites: synthesis, structure, properties and new application opportunities". *Materials Research*, vol.12, Issu1, pp.1-39.
- [2] ZhengM., Huang, Y., Z. Zhang, M. Kotaki, S. Ramakrishna; (2003) "A review on polymer Nanofibers by electrospinning and their applications in Nanocomposites" *Composites Science and Technology* vol.63,PP.2223–2253.
- [3] Guerrini, L. M., Branciforti, M. C., Canova, T., & Bretas, R. E. S. (2009). "Electrospinning and characterization of polyamide 66 nanofibers with different molecular weights". *Materials Research*, vol.12, Issu2, pp.181-190.
- [4] Beylergil, B., Tanoğlu, M., & Aktaş, E. (2017). "Enhancement of interlaminar fracture toughness of carbon fiber-epoxy composite using polyamide 6,6 electrospun nanofibers". *Journal of Applied Polymer Science*, vol.5244, Issu35, pp.45224.
- [5] Kalkan, Z. S. (2006). "The Generation and Thermo-Mechanical Characterization of Advanced Polyamide-6, 6 Nanocomposites Using Interfacial Polycondensation". Doctoral dissertation, University of Akron.
- [6] Yahaya R, Sapuan SM, Jawaid M, Leman Z, Zainudin ES. (2015). "Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf-armed hybrid laminated composite". *Materials and Design* vol. 67, pp.173-179.

- [7] Matei, S., Stoicanescu, M., & Crisan, A. (2016). Composites with short fibers reinforced epoxy resin matrix. *Procedia Technology*, vol.22, pp.174-181.
- [8] Beylergil, B., Tanoğlu, M., & Aktaş, E. (2017). Enhancement of interlaminar fracture toughness of carbon fiber–epoxy composites using polyamide-6, 6 electrospun nanofibers. *Journal of Applied Polymer Science*, vol.134, Issu35,pp.45244.
- [9] Meshram, P., Sahu, S., Ansari, M. Z., & Mukherjee, S. (2018). "Study on mechanical properties of epoxy and nylon/epoxy composite". *Materials Today: Proceedings*, vol.5, Issue 2, pp.5925-5932.
- [10] Njuguna, J., Mouti, Z., & Westwood, K. (2015). "Toughening mechanisms for glass fiber-reinforced polyamide composites". In *Toughening Mechanisms in Composite Materials* pp. 211-232.
- [11] Wu, S., Zheng, G., Guan, X., Yan, X., Guo, J., Dai, K. & Guo, Z. (2016). "Mechanically strengthened polyamide 66 nanofibers bundles via compositing with polyvinyl alcohol". *Macromolecular Materials and Engineering*, vol. 301, Issu2, pp.212-219.