Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 4, November : 2023

A REVIEW ON COMPARATIVE ANALYSIS OF TRIBOLOGICAL AND MECHANICAL PROPERTIES OF POLYMER MATRIX COMPOSITE

Swapnil N. Dhole Research Scholar, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad,Maharashtra, India dholeswapnil25@gmail.com
Shantisagar K. Biradar Department of Mechanical Engineering, Matsyodari Shikshan Santha's College of Engineering, Jalna,Maharashtra, India shantisagarbiradar@gmail.com
Girish M. Joshi Associate Professor,Institute of Chemical Technology, Jalna. Maharashtra, India, gm.joshi@marj.ictmumbai.edu.in

Abstract-
In this Study, the weight percentages of different reinforcements are added in Nylon66 parent material in order to enhance its mechanical, tribological properties of pure Nylon66 Composite. Test specimens of pure Nylon66 with different weight percentages of reinforcements are prepared by using an injection molding machine and Twin Screw Extruder. Various tests are conducted on new polymer matrix composite like tensile test, flexural test and impact test. Some tests were carried out the tribometer or pin on disk setup and its analysis through Scanning Electron Microscope (SEM) is done to study the wear charactristics of the material. The obtained result reveal that the mechanical properties as well as tribological properties of the newly prepared Nylon composite are significantly increased by the weight percentage of glass fiber, Titanium Oxide (TiO_2) and other reinforcement material , here pure Nylon indications the lowest tensile strength as compared to newly formed Nylon composite material. This study will help industries who are preparing paper making machine. In paper making machine at the time of production hot paper pulp flow from stock chamber which will reduce the life cycle of stock chamber. This new composite material will be used to prepare stock chamber and will enhance and establish good mechanical properties.

Keywords- Injection molding, Nylon66, SEM, Tribological properties, Wear rate.

1. Introduction

A composite material is made up of two or more materials that are combined to produce qualities that are superior than the individual constituents. The weight savings and relative stiffness and strength of composite materials are the key reasons for their adoption. Carbon Fiber reinforced composite, for example, is five times stronger than steel while weighing only one fifth as much. The composite business is an interesting place to work since new materials and applications are constantly being developed. Weight reduction, durability and maintenance, improved utility, and design freedom are all reasons why composite materials are employed.

Polymer-based composites have become popular in recent years when a good tribological characteristic is required. So improve properties and to lower the cost of polymer products, fillers are employed. The fillers can be in micro and nano sizes of inorganic fillers, organic fillers and metallic particulate materials. The tribological behaviour of polymers with the addition of fillers is of great interests in recent years to improve the friction coefficient and wear rate of Nylon 66.

1.1 Types of Composite Materials

Composite materials, as we all know, are made up of two or more components and have better properties than a single component. Composite materials are classed according to the matrix components they include. Metal Matrix Composites (MMCs), Ceramic Matrix Composites (CMCs), and Organic Matrix Composites are most common composites (OMCs). The term "Organic matrix composites" refers to two types of composites: Polymer Matrix Composites (PMCs) and Carbon Matrix Composites, also known as Carbon Composites. Other classification will be based on reinforcement, such like fibre reinforced composites, laminar composites, and pulverized composites.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 4, November : 2023

Fiber Reinforced Composites are even further classified into Discontinuous and Continuous Fiber Reinforced Composites. Fiber Reinforced Composites (FRC) are a type of composite material that's also made up Fibers are embedded in metal matrix; composites in Laminar Composites are layers of materials held together by matrix; and composites in Particulate Composites are particles spread or embedded in a matrix body.

There are different types of Composite material as shown in figure below:

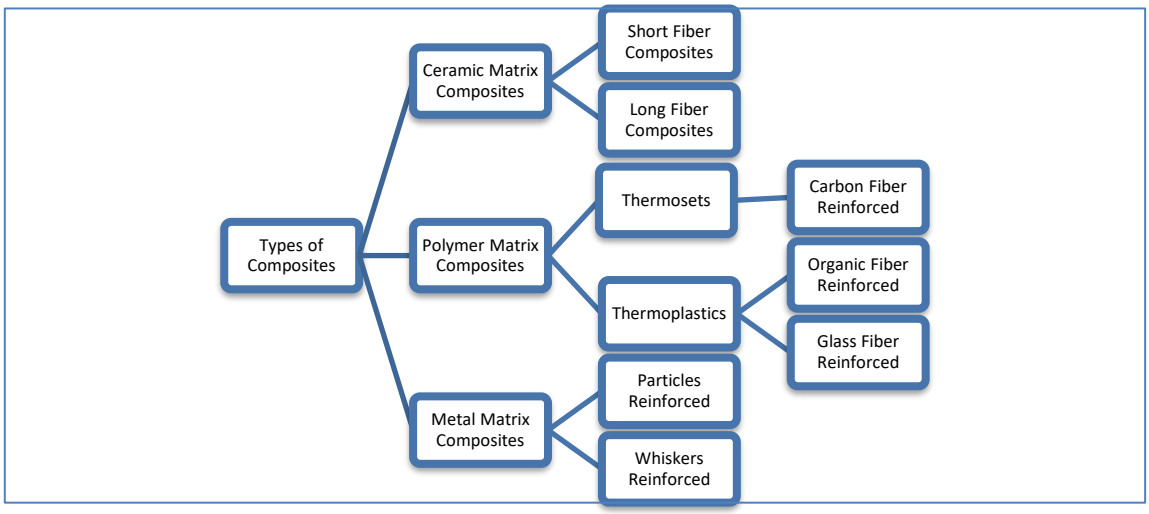


Figure 1: Types of Composites

1.1.1 Particulate Composites

A composite material having reinforcement in the form of Particles is called as Particulate Composite. A particle is non-fibrous and generally has no long dimensions, Therefore dimensions of reinforcements generally contribute to its properties in Composite. If we are using long dimension reinforcement it generally incipient cracks and otherwise, failure may occur, particularly with brittle matrices. As a result, reinforcement fibres are particularly effective in increasing the matrix's fracture resistance. Particles, in general, are ineffectual at improving fracture resistance. Rubber-like compounds in brittle polymer matrices, on either hand, enhance fracture resistance. In metallic matrices, other types of particles, such as ceramics, metals, and inorganic particles, have reinforcing effects.

1.1.2 Fiber Reinforce Composites

It is well known that measured strength of the most materials are found to be much smaller than their theoretical strength. This discrepancy in strength values is because of presence of imperfections or flaws in materials. An attempt is made to minimize this flaws helps to strengthen the material. Flaws in the form of cracks lie perpendicular to the direction of applied load are particularly determinately to strength. Fibers because of their small cross-sectional dimensions are not directly usable in engineering applications. There are therefore embedded in matrix material to form fibrous composites. Fibrous composites can be classified as single layer and multi-layer composites.

1.1.3 Advanced Fibers

A great majority of materials are stronger and stiffer in the fibrous form than as a bulk material. A high fiber aspect ratio (length-diameter ratio) permits very effective transfer of load via matrix materials to the fibers, thus taking advantage of their excellent properties. Therefore, fibers are very effective and attractive reinforcement materials. Reinforcing fibers used in advanced composites are discussed in this section.

1.1.4 Glass Fibers

Glass fibers are the most common of all the reinforcing fibers for polymer matrix composites. The principal advantages of glass fibers are the low cost and high strength. However, glass fibers have poor abrasion resistance, which reduces their usable strength. They also exhibit poor adhesion to some

polymer matrix resins, particularly in the presence of moisture. To improve adhesion, the glass fiber surface often is treated with chemicals called coupling agents. Glass fibers also have a lower modulus compared with the other advanced reinforcing fibers such as Kevlar, carbon, and boron.

Table 1: Properties of some common type of Fibers as well as conventional material is given in the table

Materials	**Tensile Modulus (GPa)**	**Tensile Strength (GPa)**	**Density (g/cm^3)**	**Specific Strength (m^2/s^2)**
E-glass	72.4	3.5	2.54	1.38
S-glass	85.5	4.6	2.48	1.85
Graphite	390	2.1	1.90	1.1
Boron	380	2.8	2.63	1.3
Silica	72.4	5.8	2.19	2.62
Tungsten	414	4.2	19.30	0.22
Beryllium	240	1.3	1.83	0.71
Steel	210	0.34	7.8	0.043
Aluminum alloys	70	0.14	2.7	0.052
Glass	70	0.7	2.5	0.28
Tungsten	350	0.1	19.30	0.057
Beryllium	300	0.7	1.83	0.38

The new material era for enhancing the mechanical as well as tribological properties of composite material has been in the trend from last few decades. In this new era many number of investigations as well as experimentations and their analysis are going on to explore the application of newly form composite material in vast fields by using different methods and techniques with minimum cost. The current study investigates the improved mechanical properties of nylon66 with different weight percentage of reinforcement like glass fiber and TiO_2. The pure nylon66 holds and exhibit some of the characteristics like abrasive resistance with toughness and strength as well as it is flexible in nature [1]. The pure Nylon66 shows lowest Stiffness and tensile modulus as compared to Composite polymer material as it shows gradual improvement in the tensile modulus as well as stiffness with the increasing weight percentage of glass fiber up to 20%. Also the Pure Nylon66 has lowest yield strength and tensile strength this properties also shows gradual increase with increase in weight percentage of glass fiber in composite material. Izod Impact test is conducted on Nylon composite material which shows that with 5% glass fiber reinforcement impact strength is lowest while with 15% glass fiber reinforcement it have highest impact strength and it is gradually decreasing after that [2]. The scratch deformation morphology of glass fiber reinforced nylon composite exhibit a strong dependence on applied load. At lower loads the glass fiber nylon composite material is characterized by a continuous plastic flow, voiding and tearing of matrix. And at higher load the composite material exhibit brittle fracture and deboned matrix has been formed [3]. The effects of strain rate, Temperature and Glass fiber content have been investigated in this research work, The newly formed glass fiber reinforced nylon results in loss of ductility and increased stiffness. As we go on increasing weight percentage of glass fiber in polymer composite higher values of tensile strength and modulus obtained with lower values of failure strain. Also strain rate has a less significant effect on nylon glass fiber composite as compared to virgin nylon therefore having higher yield stress and low failure strain. As we increase temperature it leads to more ductility and less stiffness [4]. In this study the mechanical property and tensile strength increases at 4% BN and decreases at 16% BN for BN/Nylon 6 composite. As we go on increasing weight percentage of BN at near about 12% BN we will get maximum Rockwell hardness [5]. In this study it is observed that the mechanical and tribological properties of Nylons are enhanced by the addition of various micro and nano particulate fillers. By the addition of different particulate filler

reinforcement the coefficient of friction of nylon is further improved and wear rates are decreased by the particulate filler materials. By increasing small number of particulate fillers Tensile strength, hardness and impact strength of pure Nylon improved. In some cases particulate fillers are not effective because of clustering of particles in the nylon matrix or due to the excessive humidity and processing temperature effect or due to the improper compounding of matrix and filler materials [6].here are several benefits of Composites as explained below:

- Light Weight: If there is an heavy material we can use composite material there with light weight. The lightness of composites is important in Automobiles and Aircrafts where less weight means having good fuel efficiency.
- High Strength: Most of Composites are designed stronger, as we know that Metals are stronger in all directions Composited are designed to be stronger in a specific directions.
- Strength to Weight Ratio: In order to acquire these characteristics Composite materials are designed in such a manner that it can be both stronger and light. Because of these characteristics composites are used in polymer based industry where we want high strength at the lowest possible weight.
- Corrosion Resistance: Composite materials are made to resist damage from the weather & harsh chemicals composite are used where chemicals are used
- High Impact Strength: Composites are made to absorb impact like blast from an explosion, sudden force of a bullet. Because of these characteristics of composites it is used to make bulletproof vests, shield airplanes, buildings and military vehicles from explosions.
- Durability: Structures that are made from composites are durable and have long life and need very less maintenance. In case of durability issues composites are used.
- Non Conductivity: Composites are nonconductive means do not conduct any electricity.
- Wear Resistance
- Fatigue Life
- Attractiveness
- Damping Properties
- Temperature Resistance

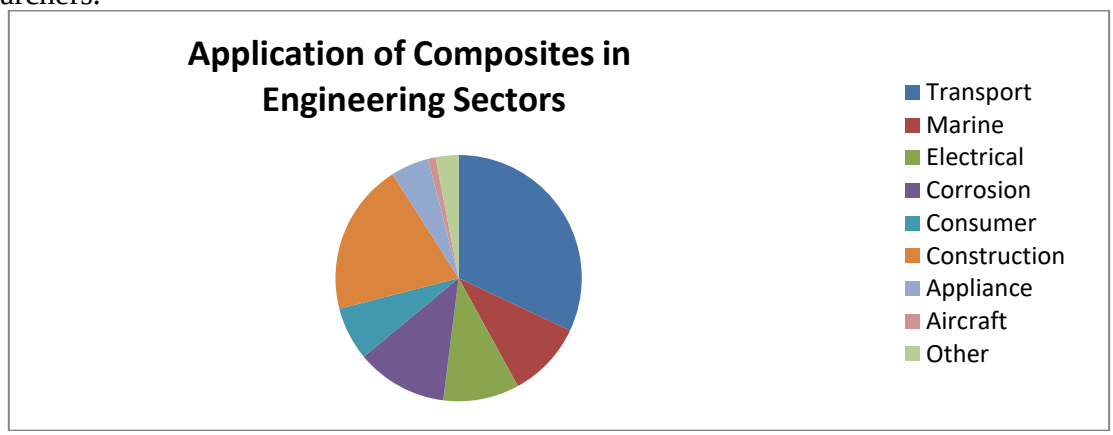
Composites have many more advantages. As listed below the various engineering Application of Composites:

Table 2: Application areas of engineered composites

Automotive	Aerospace	Marine	Medical Devices	Sports	other
Tires Belts Hoses Automotive Bodies Bumpers Body Panel Engine parts Fuel Tanks	Aircraft Tires Interiors Aircraft Components Mirror housings	Fiber Boats Boat Body Boat Building	MRI Scanners C Scanners X-ray Couches Mammography Plates Surgical Tools Prosthetics	Leather Footwear Biological shoes Skis Basketball bats Golf Clubs Tennis Rackets Bicycle Frames	Main Material Body of Industrial Equipments Components of Equipments Windmill Blades Stress Sensors Vacuum Cleaner Power tool housings Lawn Mower Hoods Cover for Mobile Phones

A composite is a material that forms with the help of of two or more chemically different constituents that are combined at a macroscopic level and are not soluble in each other to yield a useful material and to enhance the Mechanical Properties of Composite material. Composites are made to fulfill the

requirements of properties that a single material cannot fulfill. Reinforcing elements used in order to make composites are may be in the form of particles, flakes, or whiskers. Nylon composites are nowadays evolving interest due to their good strength, toughness, and low coefficient of friction and other mechanical Properties. Various fillers like micro- and nano particulates of metals and metal compounds were used to enhance the mechanical and tribological properties of nylons for many years by researchers.



Graph 1: Application of composites

2. MATERIALS AND METHODS

A. Materials

In this work, the materials used in various tests are virgin Nylon66 reinforced with different filler materials like TiO_2, Glass fiber, Fly Ash and silica fume. In this research review work Glass Fiber is the Ultimate reinforcement for all organic matrix composite materials. Reinforcement in different quantities and wt% are added in parent materials in order to form new polymer matrix composite giving enhanced mechanical as well as tribological properties. Various samples of different wt% reinforcements were injection molded or prepared by Twin Screw extruder. In this study the parent material is Nylon66 and different reinforcements are added like glass fiber having composition 0%,2%,4%,6%,15%,30% & 50% also other reinforcement added i.e. TiO_2 in 0%,2%,4% and 6% Fly ash and silica fume are added as 15% in the newly form composite in order to enhance the properties. In this study different fabrication methods are used to prepare samples this are Twin screw extruder, Injection molding process and Single screw extruder.

Nylon 66 is a semi-crystalline material has better strength, abrasion resistance and flexibility toughness. 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

Figure 2: Pellet Nylon66

Table 3: Mechanical Properties of Nylon 66 material

Material	Tensile strength (MPa)	Flexural strength (MPa)	Shear strength (MPa)	Compressive strength (MPa)	Density (Kg/m3)	Poisson's ratio
Nylon 66	82	95	0.905	66	1140	0.40

B. Methods

In this study TiO_2 nanoscale particles were prepared by sol-gel method through continuous stirring and doubling the amount of pure water by drop wise till we get white kind of mixture. After this process composites are prepared by twin Screw extruder in which the composites are obtained as wires and subjected to a cutter to prepare specimens into needed size. The obtained samples are then subjected to UTM to analyze the mechanical properties. In order to measure the wear of the specimen under wet & dry condition Pin-on-disc is used [1]. Test specimens in dog bone shape are prepared by using an injection molding machine. The mechanical properties of pure nylon 66 and nylon composites are measured under stress. Tensile testing is conducted by UTM and mechanical properties such as tensile strength, Yield strength, Ultimate strength, breaking & rupture strength are observed for both pure nylon and nylon composites [2].

The material used in this work is 30% glass fiber reinforced in pure nylon 66 prepared by using injection molding and tested for scratch test in which surface damage is done on the specimen for that purpose scratch equipment is used. The micro structural evolution is associated with the scratch process was studied using field emission scanning electron microscope [3]. Chopped E-glass and nylon 66 were used to produce composite with different wt% of glass fiber and prepared by using single screw extruder. The mechanical properties were tested on instron machine equipped with a temperature controlled chamber. The tensile test was made with a acoustic emission monitoring which is resulted monitoring a structure for active damage [4]. The matrix material used here is nylon 6 which is reinforced by material boron nitride in order to improve wear resistance of polymer matrix composite and is fabricated by Injection moulding method. The Pin-on-disc is used to measure wear and friction monitor is used to evaluate wear behavior of Nylon 6/BN polymer composites. After that Rockwell hardness test and SEM analysis was carried out to find the consequence of wear test on polymer composites.

C. Fabrication methods of Nylon Particulate Composites

While Preparing Nylon Composites the Dispersion of Nanoparticulates in a Nylon matrix is a very important step. If fillers in nylon composites are dispersed evenly good surface area form which will be responsible for enhancing the Properties of Nylon matrix composites. In general two methods are widely used for preparing Nylon matrix composites which are explained in detail below.

Twin Screw Extruder

The Twin screw Extruder provides excellent and proper mixing of reinforcement material in parent base. It is widely used to process Powder blends that need to be thoroughly mixed as well as being melted it and formed it. It consists of two parallel screws to each other which will rotate inside the cylindrical barrel. This Screw Extruder are further classified as Single Screw Extruder and Multiple Screw Extruder. In the Single Screw Extruder materials will enter from the hopper side into the feed throat and are conveyed by the rotary motion of the screw. In this case the mechanical shear which is coming from screw and thermal heat from the barrel will convert the solid polymer into the melt which will then pushed out of the die.

Injection moulding Machine

The working principle of this Injection moulding machine is similar to the working principle of syringe that we used in injections. Here it uses thrust of the screw to inject the plasticized plastic in the molten state into the closed mold cavity. In this process the products are obtained after curing and shaping. This Injection moulding process is a cyclic process.

Polymer Matrix	Reinforcement **Type** **Wt%**	Fabrication Process	Effect of Mechanical Properties	Effects of COF & WR	Any other effect	References
Nylon 66	TiO_2 0,2,4,6% Glass 0,2,4,6% Fiber	Twin Screw Extruder	Up to 4wt% increased then decreased gradually	Optimum COF Obtained at 2wt%	-	1
Nylon 66	Glass,5,10,15,20 % Fiber	Injection Molding Machine	Gradually increased with increasing GF wt%	-	20%GF shows reduced Impact strength -	2
Nylon 66	Glass 0,15,30,50% Fiber	Single Screw Extruder	Increase in wt% of GF Leads to increase in Tensile strength &Elastic modulus	-	In 30&50wt% GF rupture is observed by matrix plastication & micro cracks	3
Nylon 66	Pure Nylon Glass 10 to 20% Fiber	Injection molding machine	Lowest mechanical properties obtained with untreated sample	Decreasing moisture content decrease COF	Decreasing moisture rate improved M.P	4
Nylon 66	Fly Ash 15% Silica Fume 15%	Twin Screw Extruder	-	Fly ash filled composite show superior WR	Microploughing & Abrasive WR in Fly Ash composite	5

Table 4: various polymers, reinforcement, and reinforcements effects.

3. Results and discussions

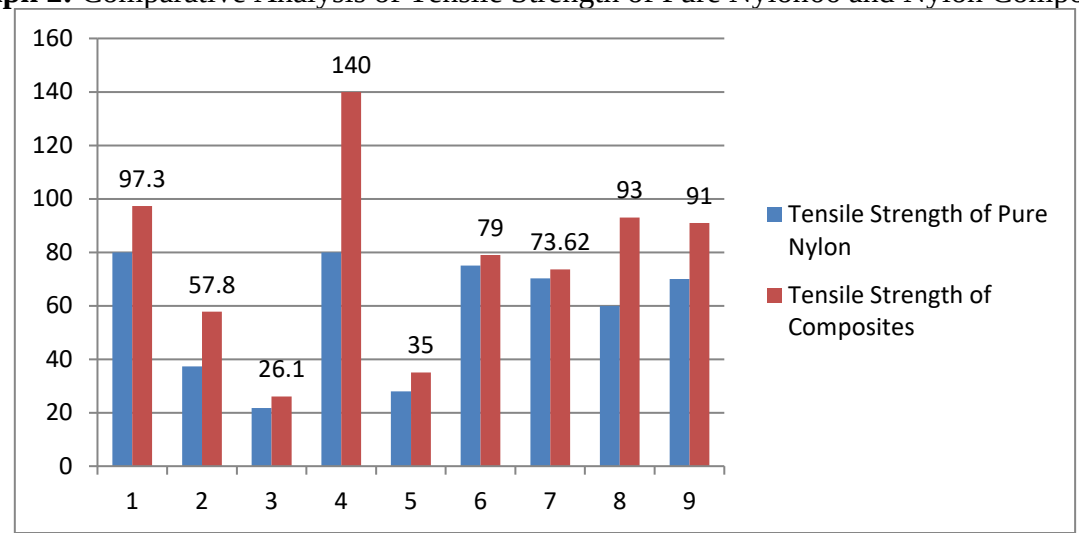
Nylons are used in many commercial as well as industrial applications like gears, belts, toys and many household types of equipment. But it cannot be used where excessive loads are applied and excessive wear occurs and this is the main cause of its failure. It is also recognized for its dye-ability, low coefficient of friction, low creep, and resistance to solvents, fuels, goals, molds, and body solutions Mechanical Properties of the manufactured composite material has been tested under various conditions and it is observed that Tensile strength is maximum at 6wt% of TiO_2 and filled with 2wt% of glass fiber and flexural strength increases from 2 to 4wt% of TiO_2 and decreases gradually. Compressive strength is maximum at 0 to 4wt% of TiO_2 thereafter decreases gradually. It is showed that at 2 and 4wt% of Nylon 66 reinforced with TiO_2 and glass fiber wear rate efficiently good than Nylon66 reinforced with TiO_2.

Table 5: Results of Mechanical Properties tested

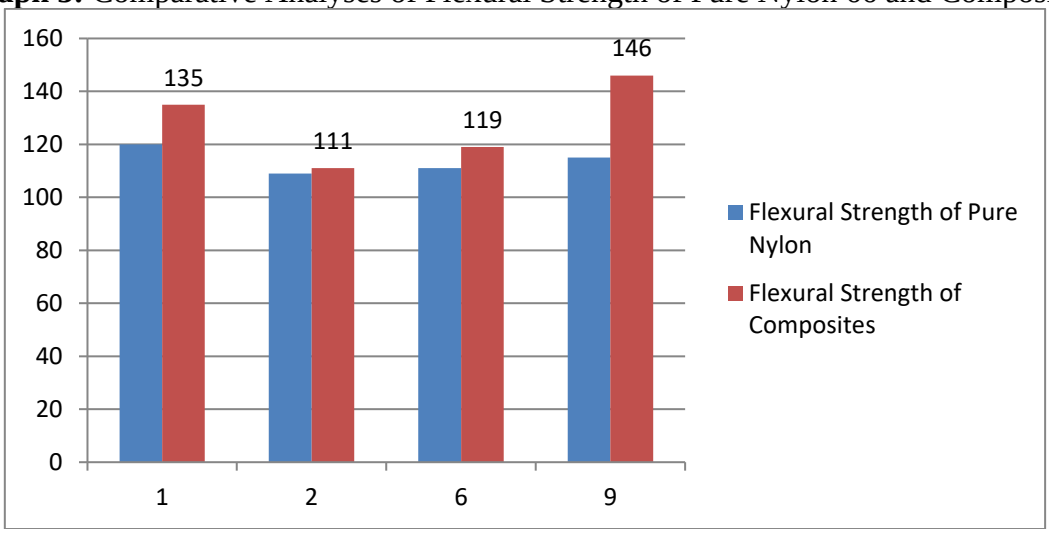
Matrix	Fillers	Maximum Tensile Strength (MPa)		Maximum Flexural Strength (MPa)		Maximum Rockwell Hardness (HRM)		Maximum Izod Impact Notched (KJ/m^2)	
		Matrix	Composite	Matrix	Composite	Matrix	Composite	Matrix	Composite
Nylon 66	TiO_2	80	89.3 for 6wt%	120	135 for 4wt%	-	-	-	-
	TiO_2+ GF	80	97.3 for 6wt%	120	140 for 4wt%	-	-	-	-
Nylon 66	GF	37.3	57.8 for 20wt%	111	119 for 20%	-	-	4.5	6.4 for 15wt%
Nylon 66	GF	21.7	26.1 for 33wt%	-	-	-	-	4.7	5.1 for 33wt%
Nylon 66	GF	80	140 for 30wt%	-	-	-	-	-	-
Nylon 66	BN	28	35 for 4wt%	-	-	80	93 for 12wt%	-	-
Nylon 66	Al_2O_3	75	79 for 6wt%	111	119 for 6wt%	97	105 for 8wt%	5.1	6.02 for 6wt%
Nylon66	GRF	70.21	73.62 for 1wt%	-	-	-	-	-	-
Nylon 6	Al_2O_3	60 70	93 for 3wt%	-	-	-	-	-	-

Nylon6	Clay Nano Particles	91 for 5wt%	115	146 for 5wt%	-	-	90	91for 5wt%

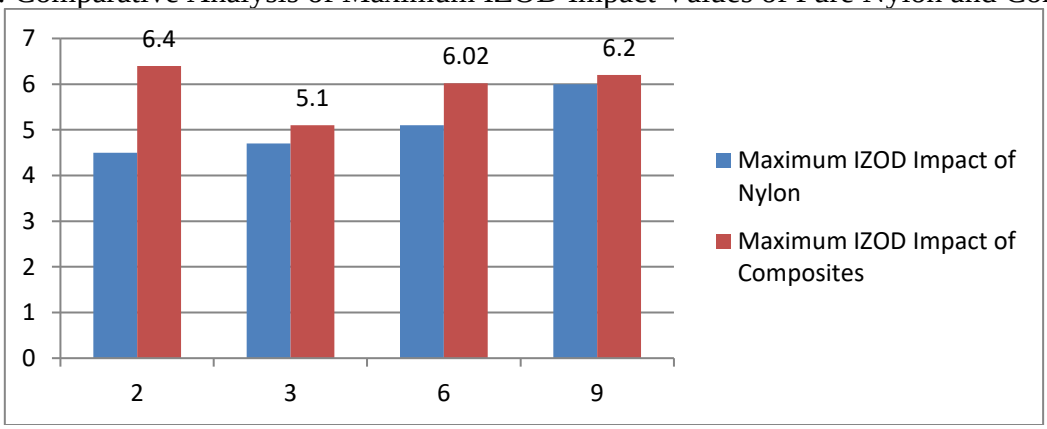
Graph 2: Comparative Analysis of Tensile Strength of Pure Nylon66 and Nylon Composites



Graph 3: Comparative Analyses of Flexural Strength of Pure Nylon 66 and Composites



Graph 4: Comparative Analysis of Maximum IZOD Impact Values of Pure Nylon and Composites



4. Conclusions

The influence of different weight percentages of different types of reinforcement on the tribological and mechanical properties of nylon66 composites was investigated. The following conclusions are drawn from the present research study:

1. It is visible that the mechanical and tribological properties of nylons 66 are enhanced by the various micro- and nanoparticulates fillers. The coefficient of friction of nylons is further improved and wear rates are decreased by the adding the reinforcements.
2. It was determined that some of the mechanical properties like Tensile strength, Flexural strength, Tensile modulus, impact strength , modulus and Compressive strength increases are improved by addition of different types of composite while compared with nylon66 pure material
3. The examination for mechanical and tribological properties was gone through in detail. It was determined that some of the mechanical properties like Tensile strength, Flexural strength, Tensile modulus, Flexural modulus and Compressive strength. Pure nylon 66 material shows the lowest mechanical and tribological properties and the nylon composite shows gradual improvement in the mechanical and tribological properties with the increased content of reinforcement like TiO_2, glass fibre etc.
4. Metallic fillers in nylons66 are generally useful in improving a few of the mechanical properties, thermal properties, and wear rates. Metallic compounds like oxides and nitrides are beneficial in enhancing the tribological properties of nylons. Still, the results may vary according to the process and process parameters used for the fabrication of composite. Nylon composite's fabrication process requires special attention to the environmental humidity as it can absorb moisture from the environment which can deteriorate the properties of the final product. Drying of nylon is essential before the compounding of matrix and fillers as well as before injection moulding of products.
5. Conflicts of interest

5. Acknowledgment

I would like to express my deepest gratitude and sincere thanks to my guide **Dr. S.K.Biradar**, Principal of Matsyodari Shikshan Sanstha's College of Engineering and Technology Nagewadi, Jalna for his valuable time and keen interest in my review paper. His intellectual advice has helped me in every step of my review paper work and motivated my efforts.

6. References

[1] Crivelli Visconti I. Engineering potential of composite materials. Polym. Eng. Sci. 1975, 15, 167–177.
[2] Agarwal B. D., Broutman. L. J. Analysis and Performance of Fiber Composites 2nd ed.; John Wiley & Sons, 1990, 2–16. https://doi. org/10.1017/S0001924000023757.
[3] Schwartz M. M. Composite Materials Handbook; McGraw-Hill: New York, 1984.
[4] Eckold G. C. Design and Manufacture of Composite Structures; Elsevier: Cambridge, 1994.
[5] Hollaway, L. C. The evolution of and the way forward for advanced polymer composites in the civil infrastructure. Construct. Build. Mater. 2003, 365–378. https://doi.org/10.1016/S0950-0618(03) 00038-2.
[6] PNE Naveen, Bhau Kiran Goriparthi, "Evaluation of mechanical properties on Tio2/GF reinforced nylon66 composites", Materials Today: Proceedings, 2019
[7] D M Nuruzzaman, AKM Asif Iqbal, IOP Conf. Series: Materials Science and Engineering 114 (2016)
[8] N. L. Surampadi, N.K.Ramisetti, Material Science & Engineering, (2007) 230-235
[9] B.Mouhmid, A. Imad, Polymer testing, Science direct, 2006, (544-552)
[10] K.Shiva Kumar, A.Chennalesava Reddy, Results in Materials, Science Direct, 2020
[11] Kawaljit Singh Randhawa & Ashwini D. Patel Polymer Engineering, 2021; 41(5): 339-355

[12] J.Charles, E-Journal of Chemistry, FTIR and Thermal Studies on Nylon-66 and 30% Glass Fibre Reinforced Nylon-66, ISSN: 0973-4945

[13] Saheb, D. N., Jog J. P. Natural fiber polymer composites: a review. Adv. Polym. Technol. 1999, 351–363. https://doi.org/10.1002/ (SICI)1098-2329(199924)18:43.0.CO;2-X.

[14] Miracle D. B., Donaldson S. L., Henry S. D., Moosbrugger C., Anton G. J., Sanders B. R., Hrivnak N., Terman C., Kinson J., Muldoon K., Scott Jr W. W. ASM Handbook; Materials Park, OH: ASM International, 2001, 21, 107–119

[15] Sviridyonk A. I. Self-lubrication mechanisms in polymer composites. Tribol. Int. 1991, 24, 37–43.

[16] Sliney H. E. Solid Lubricants. 1991. 12. Briscoe B. J., Sinha S. K. Wear of polymers. Proc. IME J. J. Eng. Tribol. 2002, 216, 401–413. 13. Rees B. L. Static friction of bulk polymers over a temperature range. Research 1957, 10, 331–338.

[17] Lancaster J. K. Relationships between the wear of polymers and their mechanical properties. In Proceedings of the Institution of Mechanical Engineers, Conference Proceedings; Sage UK: London, England: SAGE Publications, Vol. 183(16), 1968; p. 98–106.

[18] Li X., Gao Y., Xing J., Wang Y., Fang L. Wear reduction mechanism of graphite and MoS2 in epoxy composites. Wear 2004, 257, 279–283.

[19] Wang S., Ge S., Zhang D. Comparison of tribological behavior of nylon composites filled with zinc oxide particles and whiskers. Wear 2009, 266, 248–254.

[20] Wang J. X., Gu M. Y. Investigation of the influence of CuO filler and carbon fiber on wear and transfer film of nylon composites. J. Appl. Polym. Sci. 2004, 91, 2397–2401.