IJARSCT
ISSN: 2581-9429
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Volume 5, Issue 10, April 2025
Impact Factor: 7.67

An Analysis of Glass Fiber Reinforced Polyamide 66 and PTFEs Tribological Performance

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Abstract: *Thermoplastic polymer composites are widely used as structural materials in automotive, manufacturing, aerospace and chemical industries to provide lower weight alternatives and self lubrication to traditional metallic materials. These applications in the many industry sectors are concentrated on tribological machine parts, such as gears, cams, bearings and seals, due to their many advantages of polymer composites as self lubrication. The main advantages of these polymers are high wear resistance, cost, weight, silent operation and manufacturability at non-lubricated dry conditions in journal bearing materials.*

To meet the combination of light weight and high strength demands polymer-based materials are increasingly applied in many industries. PA66 has been reported to have superior wear resistance to other polymers due to its ability to form a thin and uniform transfer film while sliding against steel counterparts. However, these polymer materials have low mechanical properties, such as low mechanical strength, low thermal conductivity and large thermal expansion. Therefore PA66 polymer bearings have limited the wide applications. In order to overcome these low mechanical properties of neat polymer, reinforcement fiber are usually embedded in polymers to make composites. Glass fibers which are short fiber reinforcements have been successfully used to improve the strength to high pressure, high load carrying capacities and stiffness. In addition, to effectively reduce the coefficient of friction of journal bearings, PTFE additives are embedded in PA66 composites. PTFE has low coefficient of friction and high thermal stability.

Keywords: Additives, Polyamide, polymer, Sliding Wear

I. INTRODUCTION

Polymeric materials have been widely used in industry. There are a lot of reasons to use the polymeric materials as provide lower weight alternatives and self lubrication instead of traditional metallic materials. The main advantage of these polymers is self lubrication and corrosion resistance. However, the polymer materials have low mechanical properties, such as low mechanical strength, low thermal conductivity and large thermal expansion. Therefore polymer bearings have limited the wide applications. In order to turn disadvantages to advantages, reinforcement fiber are usually embedded in polymers to make composites. Glass fibers and carbon fibers which are short fiber reinforcements have been successfully used to improve the strength to high pressure. In addition glass fibers improve the load carrying capability and the thermal conductivity. These are a positive effect to lowering wear rate of pure polymer. Therefore the thermal conductivity which is provided by glass fiber to polymer, gives good wear performances to polymer materials.

II. LITERATURE REVIEW

This chapter outlines some of the recent reports published in various literatures on composites with special emphasis on dry sliding wear behavior of fiber reinforced polymer composites at normal temperature. Particularly in aerospace applications research is underway worldwide to develop newer composites with varied combination of fiber and filler so as to make them unable under different operational conditions. The improved performance of polymer composites in

DOI: 10.48175/IJARSCT-25660

IJARSCT

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engineering applications by the addition of filler material has shown a great promise and so has become a subject of considerable interest.

Mehmet Turan Demirciet. al [1] has reported in Materials and Design 57 (2014) 560–567 the effect of sliding velocity, bearing pressure and temperature on friction and wear of PA66 (Polyamide 66), PA66 + 18% PTFE (Polyamide 66 + 18% Polytetrafluoroethylene) and PA66 + 20% GFR + 25% PTFE (Polyamide 66 + 20% glass fiber + 25% Polytetrafluoroethylene) journal bearings were examined at ambient conditions. The results of experiments are presented in graphics which proves that friction coefficients, contact temperatures and wear rates are affected by forming film, increasing temperature, pressure and velocities depending on GFR and PTFE mechanical properties. There are many factors and their widely fluctuation characters on the polymer friction and wear behaviors. The best wear behavior was seen at the PA66 + 20% GFR + 25% PTFE journal bearing. Today thermoplastic polymer composites are widely used as structural materials in automotive, manufacturing, aerospace and chemical industries to provide lower weight alternatives and self lubrication to traditional metallic materials. These applications in the many industry sectors are concentrated on tribological machine parts, such as gears, cams, bearings and seals, due to their many advantages of polymer composites as self lubrication. The main advantages of these polymers are high wear resistance, cost, weight, silent operation and manufacturability at non-lubricated dry conditions in journal bearing materials. Injection-moulded Polyamide 66 (PA66) polymer is primarily used in engineering plastics. PA66 has been reported to have superior wear resistance to other polymers due to its ability to form a thin and uniform transfer film while sliding against steel counterparts. However, these polymer materials have low mechanical properties, such as low mechanical strength, low thermal conductivity and large thermal expansion. Therefore PA66 polymer bearings have limited the wide applications. In order to overcome these low mechanical properties of neat polymer, reinforcement fiber are usually embedded in polymers to make composites.

Sung Soo Kim et. al [2]has reported in his literature the friction and wear of short glass fiber reinforced polyamide 12 (PA12) were investigated. The behavior of the fibers on a sliding surface and their effect on the friction and wear were studied in terms of the amount and orientation of the fibers in the composite. Results showed that the friction level and wear resistance were strongly affected by the fiber content, and glass fiber patches produced on the sliding surface played important roles in the wear resistance of the composite. The optimum fiber content for the best wear resistance of the PA12 composite was approximately 30 wt.% and higher fiber contents had no added effect on the wear amount. The applied load also strongly affected the wear resistance due to the increase in temperature at the sliding interface, and an increase in rapid wear was observed when the interface temperature increased above the glass transition temperature of PA12. On the other hand, the fiber orientation had less effect on the friction and wear of the composite compared to the fiber content and applied load. Based on the behavior of glass fibers on the sliding surface and wear debris analysis, the wear mechanism of the PA12 composite is discussed. Tribological applications of polymeric materials have been expanded considerably over the last few decades because the demands for weight and cost savings have forced the replacement of metallic components with polymer based materials. The components made of polymers are, therefore, frequently found in automotive parts and electronic devices and their applications have been spread to various structural and functional components. However, the mechanical properties of a monolithic polymer are often insufficient for the component to withstand a high loading condition, and the polymer composites strengthened with reinforcements have been developed to meet the requirements of high strength and wear resistance.

Hayrettin Düzcükoglu et. al [3] has reported in Materials and Design 30 (2009) 1060–1067 that Under heavy loading and large numbers of revolutions, the most commonly encountered gear damage is the thermal damage that is caused by an accumulation of heat on the surface of the tooth. The maximum Hertzian surface stress occurs at the single tooth pair contact region. The aim of this study was to delay the formation of thermal damage in the region of single tooth meshing by decreasing the Hertzian surface pressure by increasing the tooth width. The F/b (N/mm) tooth load was decreased in the single tooth pair contact region. Experiments show that the appearance of thermal damage is delayed for the width-modified gear teeth in comparison with unmodified gear teeth. Gears are the basic power and motion transfer elements used in every machine. The most important properties in gear design are wear resistance, cost, weight, silent operation and manufacturability. When analyzing gear designs, breakage at the tooth root, thermal damage, pitting, and wear should be considered. Plastic gears have some advantages, such as silent operation durability against

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corrosion, low weight, easy and quick production, and working without lubrication. However, one of their main limitations is their low allowed operational temperature and load. Because of the poor heat conductance of plastic gears, the material accumulates heat and softens quickly. As a result, the plastic gear contact surface temperature becomes high enough to dramatically increase the likelihood of local softening and surface wear. Over the past few decades, a considerable number of studies have been conducted on the performance of plastic gears. Plastic gears made by injection molding, primarily polyacetal (POM), polyamide (PA), and polycarbonate, are used in copy machines, fax machines, and printers. Polymer composite gears are used for many light and medium duty power transmission applications, as well as for motion transmission applications. Components made from injection-molded polyamide 66 (PA66) and PA66 composites running in non-conformal rolling–sliding contact are widely used in engineering. Polyamide 66 is a widely used polymer for gear and bearing applications, and its tribological properties have been studied by many researchers. In this research, the influence of reinforcement on the fatigue performance, tooth damage, and wear resistance of plastic gears is well discussed. The heat conduction of the plastic gears is low, and heat therefore accumulates in the regions of power transmission on the tooth surface in thermal failures. As the mechanical resistances of plastic gears are dependent on temperature, it is necessary to decrease the gear temperature or to create a smooth heat distribution. Plastic gears that cooperate with steel can partially serve this aim.

Rainer Franke et. al [9] in this topic author deals with the formation of new PTFE polyamide materials by reactive extrusion. The new type of formed PTFE polyamide compound shows very good material properties. Recently it has been revealed that carboxylic acid groups exhibit a very high reactivity under polyamide melting conditions. PTFE micro powders functionalized by carboxylic acid groups are the base for the block copolymer formation in polyamide melts under defined process conditions. Such functionalized micro powders are formed from virgin PTFE by electron irradiation in the presence of oxygen. These new PTFE polyamide materials can be processed easily using commercial (common) process equipment like twin-screw extruders and injection molding. Many experimental investigations have been performed under dry sliding friction on PA 6, PA 6.6 and PA 12 compounds with PTFE weight portions between 3.3 and 50%. They show low coefficients of friction and low specific wear rates. The wear resistance of newly developed PTFE polyamide compounds is comparable with commercially available mechanically or physically produced PTFE and PEAK compounds. Thermoplastic materials have been used as bearing materials for a long time. Self-lubricating characteristics and low cost make polymer materials interesting, particularly for bearings with minor demands. If the bearing requires higher loads and small clearance over the entire lifetime, pure polymer materials are less suitable because of their lower mechanical strength. The solution for these applications is the production of compounds especially reinforced with different materials and additives. Reinforcement increases the tensile and compressive strength of such materials. The combination with special additives can result in a reduction of the coefficient of friction and the increase of thermal conductivity, insofar as such compounds are produced by mixing and sintering of the individual components or by melt processing. This study presents newly developed PTFE–PA compounds. It concerns materials with improved characteristics, manufactured by chemical bonding of polytetrafluoroethylene (PTFE) and polyamide (PA) by reactive extrusion. They allow smooth processing by extrusion and injection molding under polyamide processing conditions.

R. Franke, et. al [10] has worked on the sandwich molding process for the production of multi-component shaped parts is gaining increasing importance. With this procedure different materials, such as functional and construction materials, can be combined to form composite construction parts with good load-bearing characteristics. The investigations were performed with a pure PA 66 and 4 different modified PTFE-PA 66 compounds with a PA 66 injection type matrix. The virgin PA 66 granulate was processed without extrusion directly by injection molding under usual processing conditions of PA 66 materials without changes of the technical parameters as compound material and as skin material of the sandwich molded specimen. Compound materials were processed with irradiated PTFE micropowder by reactive extrusion to form chemically bonded PTFE-PA 66 compounds with 20 wt% of irradiated PTFE. These compound materials were also used as skin materials for sandwich molding. The compound material was reinforced with 10 vol. bronze powder or by aramide short fibers. The tribological investigations were performed as load increment tests using a ring-on-disk test machine. The pressure was increased in each step after a testing time of t = 2 h. For the sliding speed of v low = 0.01 m/s the pressure increment was p = 2MPa and for the higher sliding speed of v high = 0.65 m/s p =

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0.5MPa. The tests were carried out at room temperature. The investigations of sandwich compounds with chemically bonded PTFE-PA 66 surface material and glass-fiber reinforced core at different pressures and sliding speeds under unlubricated condition show a decrease of the specific wear rate k in comparison to compact material of the same composition more than the half. The investigation of the morphology of sandwich specimen cross-sections resulted in the fact that with sandwich molding a characteristic property gradient in the function layer is developed which leads to an optimal adjustment of the friction partners during the running-in process. The glass -fiber reinforced core gives a sufficient stiffness effect of the part even at higher pressures. On the other hand the addition of bronze powder as filler or aramide fibers as reinforcement material in compound PTFE-PA 66 materials results in compounds with high mechanical strength and low wear.

AbdulkadirGulluet. al [12] has reported in Materials and Design 27 (2006) 316–323 experimental work, which influence of silane coated glass fibres added to polypropylene (PP) and polyamide 6 (PA6) plastics was investigated. These plastics were reinforced with (15 and 30 wt %) silane coated glass fibres. For this purpose, a die was designed and manufactured to produce tension and notched impact species using various injection parameters. Based on the results of this work, which investigates the influence of fibre reinforcement and injection parameters on the tensile strength and impact strength, PP and PA6 plastics reinforced with glass fibre exhibited improvement in their mechanical strength with the fibre reinforcement. However, improvement in the mechanical strength did not show a linear relationship with the fibre weight fraction on account of inhomogeneous fibre distribution and fibre fracture. In addition, tensile strength increased with increasing injection feeding zone temperature and decreased with increasing injection speed and extruder screw speed. Plastics, invented towards the end of 18th century and after the World War II, used as alternative to natural sources and materials, have become an indispensable part of human life. The use of plastics is increasing due to their easy formability, light weight, resistance to various chemical materials, low electrical conductivity, ability to be transparent and to be coloured and low cost.They are used in nearly all industries. Toys, household items, and packaging industries are some of them. As plastics can be obtained at laboratory conditions, there is no limit to their types, quality, mechanical and physical properties. As a minor change in the processing parameters can influence the properties of plastics, they can be tailored according to the purpose by controlling these parameters. This flexibility makes plastics engineering materials of the future. Plastic materials are continuously replacing metal parts in the manufacture of machine parts.

L. Chang et. al [13] has worked on the tribological properties of polyamide 66 (PA66) composites, filled with TiO_2 nanoparticles, short carbon fibres, and graphite flakes, were investigated. Sliding tests were performed on a pin-on-disk apparatus under different contact pressures, p, and sliding velocities, v. It was found that nano-TiO_2 could effectively reduce the frictional coefficient and wear rate, especially under higher pv (the product of p and v) conditions. In order to further understand the wear mechanisms, the worn surfaces were examined by scanning electron microscopy and atomic force microscopy. A positive rolling effect of the nanoparticles between the material pairs was proposed which contributes to the remarkable improvement of the load carrying capacity of polymer nanocomposites. Over the past decades, polymer composites have been increasingly applied as structural materials in aerospace, automotive and chemical industries, providing lower weight alternatives to traditional metallic materials. Numerous these applications are concentrated on tribological components, such as gears, cams, bearings and seals, etc., where the self-lubrication of polymers and polymer composites is of special advantage. The features that make polymer composites so promising in industrial applications are opportunities to tailor their properties with special fillers. For instance, short fibre reinforcements, such as carbon and glass fibres, have been successfully used to improve the strength and therefore the load carrying capacity of polymer composites. Solid lubricants, e.g., polytetrafluoroethylene (PTFE) and graphite flakes, were proved to be generally helpful on developing a continuous transfer film between the two counterparts and accordingly reduce the frictional coefficient. Recently, nano-scale inorganic particles are under consideration. Attempts give special hints that this method is promising for new routes of wear resistant materials even at very low filler content (about 1–4 vol%) [7,8]. However, the mechanisms by which nanoparticles in modifying the tribological performances in polymer composites are not fully understood. While, most polymers with special fillers can provide low frictional coefficient and low specific wear rate.

M. Palabiyiket. al [18]has worked on the mechanical and tribological behaviors of polyamide 6 (PA6) and high density polyethylene (HDPE) polyblends made using maleic anhyride polypropylene as the compatibilizing agent were studied. The compositions investigated for tribological behavior were 80 wt.% PA6–20 wt.% HDPE and 60 wt.% PA6–40 wt.% HDPE. The polyblends were reinforced with glass fiber (GF) and filled with polytetrafluoroethylene (PTFE) and copper oxide (CuO). The polymeric materials were blended using a modular intermeshing co-rotating twin-screw extruder. The reinforced composite specimens with different fiber proportions were made in a reciprocating screw injection molding machine using the blended materials as the feed stock. The friction and wear experiments were run under ambient conditions in a pin-on-disk machine with the polymer pin riding on the flat surface of a steel disk at a sliding speed of $1ms^{-1}$ and under a nominal pressure of 0.64MPa. With fiber reinforcement, the tensile strength of a polyblend consisting of 80 weight percent PA6 and 20 weight percent HDPE rose, but the material became brittle. The maximum reductions in wear and the coefficient of friction were obtained by filling the polyblends with 10 wt. % PTFE. Fiber glass reinforcing did not reduce the polyblend's already low wear rate. Because they provide combinations of qualities that metals, ceramics, and polymers cannot, composite materials find use in a wide range of products. For sliding components, polymer composites have mostly supplanted conventional metallic materials. Studies of the tribological behavior of polymer composites have become commercially necessary due to their growing application in sliding components. Polyblending provides an alternative to copolymerization for the creation of novel materials. The composition of new materials can be adjusted to have a suitable combination of polymer characteristics for polyblending. Fillers and reinforcements can improve characteristics.

S.N. Kukurekaa et. al [20] has worked on an investigation into the effect of fibre reinforcement on the friction and wear of PA66 in rolling–sliding contact is reported. Three different kinds of short fibers—glass, carbon, and aramid—were investigated using composites that ran against identical materials in a twin disc machine. He found that the aramid fibre reinforcement did not significantly alter the friction of the matrix material. Nonetheless, the coefficient of friction was significantly decreased by both carbon fiber and glass fiber reinforcement. Wear of the aramid and carbon fibre composites was essentially linear with time and generally around ten times greater than that of the unreinforced material. The initial era of glass fiber composite wear was complex, with a wear rate comparable to that of unreinforced material. After a significant depth of wear had occurred the wear rate changed to a value similar to, but slightly higher than, that of the other reinforced materials. One of the main advantages of fiber reinforcement, especially glass, seems to be that it lowers the coefficient of friction and permits the use of materials for heavier tasks without going over the matrix's softening point. However, a higher wear rate and a shorter component life come with the duty increase.

III. RESEARCH GAPS

In first paper mehmut turan has taken three samples PA66 (Polyamide 66), PA66 + 18% PTFE (Polyamide 66 + 18% Polytetrafluoroethylene) and PA66 + 20% GFR + 25% PTFE (Polyamide 66 + 20% glass fiber + 25% Polytetrafluoroethylene) journal bearings were examined at ambient conditions. In this samples only 20% of glass fibre has been used we can increased its percentage to increase load carrying capacity In next paper Sung Soo Kim has studied samples and found out that upto 30% of glass fibre can be added. But author has not added PTFE in his samples so this was limitation in his paper.

Rainer Franke has taken the samples of combination of PA66 and PTFE, found out that upto 25% of PTFE can be added to PA66. But author missed out the Glass fibre which can increase load carrying capacity. From these gaps we can have a new combination of material which can have good tribological character.

So new combination of material will be 1.PA66+25%PTFE+25%GF

2. PA66+25%PTFE+30%GF
3. PA66+25%PTFE+35%GF

So by changing glass fibre content we can improve the wear.

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IV. EXPERIMENTAL WORK

The prepared samples were used for tribological test for elevated temperature at S.N.D. College of Engineering Yeola. Maharashtra. A pin-on disc device was used in accordance with ASTM D2538 and ASTM D2396. Banglore-based DUCOM Instrument provided the test rig, shown in fig 1.

Initially the calculations were done before test. Specially the wear tests were conducted for non- lubricating reciprocating compressor piston ring. The basic aim was that to minimize wear rate and find better material for piston rings of non-lubricating reciprocating compressor. The value of contact pressure were selected with no lubricating air compressor application which works at working pressure at 15MPa and sliding velocity were selected to 5.4m/s. To evaluated the durability at elevated of material at elevated temperature, the pin was kept in the temperature controlled environment ie Pin holder or collet was kept inside the collet holder which is has provides heating device. The electrical heating device was controlled by microcontroller in various ranges. The variation in the temperature of collet is in the steady sate was less than ±5°C.during the test load values were selected 49.05N. and temperature were kept from 100°C to 250°C as glass transition temperature of PA66 is 143°C and melting temperature is 343°C as per standard data supplied by Victrex. Also another aim for keeping the temperature from 100°c to 250°c has taken specific application of ATLAS CAPCO non lubricating reciprocating air compressor. The generally discharge temperature of compressed air vary from ambient to 70°C as compressor run continuously long time. Also similarly all parameter like sliding velocity, load and temperature parameter were selected on basis of considering same application. During the test first specimen were holed in a temperature environment and initial temperature was sated at 125°C , load 49.05 N and sliding velocity 5.4m/s. as an input parameter for the measuring of frictional force and wear. The frictional coefficient was measured during the test and computed as a ratio of the normal load to the tangential force. This is also monitored by placing load cell transducers. The test temperature was monitored by an iron-constantan thermocouple positioned in the hole of collet where pin specimen was fitted. The reduction in height of the specimen was measured by a displacement transducer, could be used to characterize the wear process. However, the potential thermal expansion of the sliding counterparts had an impact on the measurement's accuracy.

Fig. 4.1 Pin on Disc Tribometer

TABLE 4.1 Tribo-Properties of Different Composites at Elevated temperature.

Comparative study of three material were studied from table 1. It was observer that with an addition of glass fibre there is drastic change in wear rate. After studying this material it is found that Material PA66+25%PTFE+ 30%GF shows best wear rate, it has very low coefficient of friction and also has very low wear.

DOI: 10.48175/IJARSCT-25660

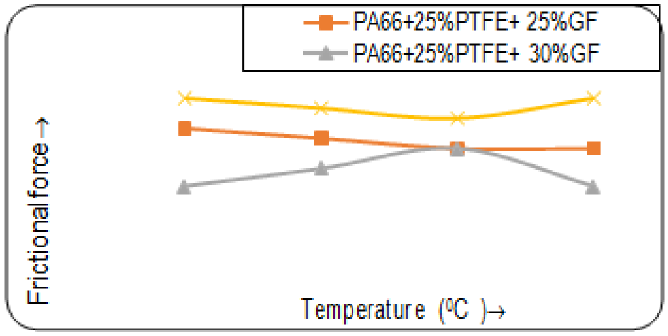

Fig 5.1 Effects of temperature on Frictional force

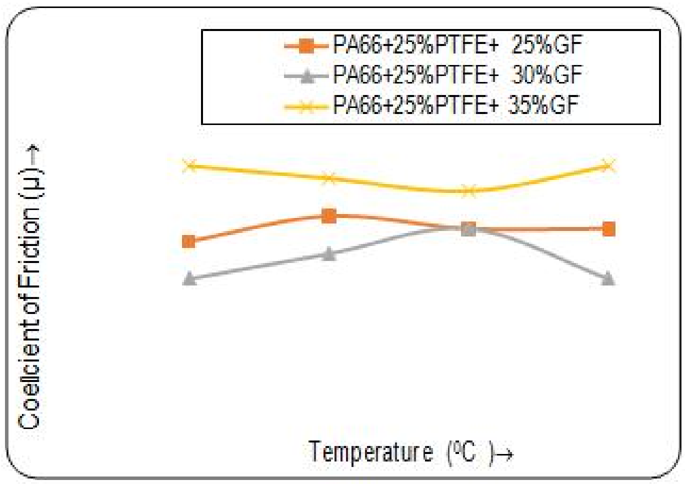

Fig 5.2 Effects of temperature on coefficient of friction

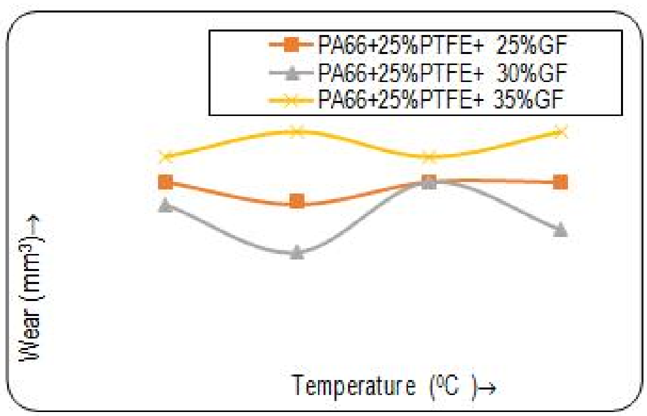

Fig 5.3 Effects of temperature on wear

V. CONCLUSION

The tribological properties of Polyamide, PTFE, Glass fibre combination was studied at low temperature as well as at elevated temperatures. From the results the following conclusion are drawn. In comparative study of PA66+25%PTFE+ 25%GF, PA66+25%PTFE+ 30%GF, PA66+25%PTFE+ 35%GF. It was observed that wear PA66+25%PTFE+ 30%GF shows the best wear resistant at room temperatre as well as at high temperature. From the result it is clear that upto 30%

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ISSN: 2581-9429

Volume 5, Issue 10, April 2025

Impact Factor: 7.67

of glass fibre can be added to polyamide and PTFE combination and further addition there is no positive effect. From the result it is clear that PA66+25%PTFE+ 30%GF can be used at room temperature and also at elevated temperature.

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