Chapter 47
The Mechanical Behavior and Tribological Characteristics of Nylon-$CaSO_4$ Polymer Composites

S. Sreenivasulu and A. Chennakesava Reddy

Abstract In this paper, Nylon-$CaSO_4$ polymer composites are investigated with respect to their mechanical behavior and tribological characteristics. An injection molding machine is used to make the composites. Taguchi L9 design of experiments is used to examine wear qualities and the impact of process factors such as normal load, sliding distance, speed, and percent filler material. To determine the effect of filler in composites, tensile tests are performed by increasing the filler content in the composition. The worn surface is examined using SEM for better findings. The ANOVA is used to examine the composite's contribution to the input process parameters. This paper contributes to a decrease in ultimate strength due to increased calcium sulfate content in the composites, as well as a variation in wear rate of 73.41% because of sliding speed.

47.1 Introduction

Polymer composites are commonly used in the manufacturing of industrial hardware. The majority of composites utilized have strong mechanical and tribological qualities, are lightweight, and have high ecological and synthetic resilience. Nylon 6 is a semi-glass-like thermoplastic design that is well-known in most companies due to its high quality, uniqueness, and substance resistance. It has a wide range of uses in modern airplanes, machines, cars, and other commercial products where creep resistance, solidity, and durability are desired. Coordination of inorganic particle fillers has shown to be a viable strategy for increasing mechanical properties, particularly Nylon

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toughness. The best nanoparticle filler materials for composite polymers can increase the mechanical and tribological characteristics of the material.

The grafting polymerization of nanoparticles such as nano silica into polypropylene composite (PP) produces a toughening and reinforcing effect. This has an effect on composite tensile strength as a function of load [1]. One way to improve thermoplastic polyamides' tribological parameters (such as wear and coefficient of friction) is to introduce second phase nanoparticles (PA). The smooth surface of nanocomposites is obtained as a result of this, showing good tribological qualities [2]. Tensile strength increases during curing as a result of improved interfacial adhesion. Glass fiber is an effective epoxy resin reinforcement for high-performance applications. The mechanical qualities are increasing dynamically [3].

Researchers used Nylon 6/Teflon as a matrix and graphite as a filler to make thrust washers and sleeve bearings [4]. Short fiber-reinforced thermoplastic composites are often employed in a variety of areas, including aerospace and aircraft as well as the automobile industry [5]. The mechanical properties of thermoplastic polymers were also enhanced by adding various filler components. In combination with nanoparticle fillers such as SiC [6], Al_2O_3 [7], and Fe_2O_3 [8], and in combination with other polymers, nylon-6 provides considerable benefits. The modulus and yield strength of polyamide 6/layered-silicate nanocomposites (PLSN), and Si_3N_4 rise with an increase in filler content, according to tensile tests [9]. According to mechanical tests, increasing carbon fiber content leads to better modulus, tensile strength, and hardness, but there is a decrease in strain at break value [10]. The submicron particles and microparticles can improve mechanically and wear opposition of the chemosphere-filled vinyl ester composites. The submicron-sized particles are more successful in improving the wear opposition than the micro-sized particles [11]. Short fiber-fortified polymers (SFRPs), the tribological execution of SFRPs, can improve by using nanoparticles due to their grating diminishing capacities, especially under silly stacking conditions [12]. Strategy untreated and surface-treated TiO_2 are produced using anionic ring-opening polymerization of e-caprolactam by rotational molding method. Melting temperature, average molecular weight, water observation, and conversion degree decreases from the actual value [13]. The addition of iron oxide to the Nylon 6/Teflon grid improves tensile strength and hardness while reducing the ductility of the Nylon/Teflon polymer composites [14]. At 4 wt% Si_3N_4, tensile strength is highest and decreases with increasing presence. Nylon-6/Si_3N_4 composites are hard (weighted at 16%) and wear less (up to 4 wt% Si_3N_4) than 12 or 20 wt% Si_3N_4. It can be seen from SEM images that most of the variation in nanoparticles comes from the matrix. SEM images are useful in comprehending composite surfaces with different inputs**.** As a result of Taguchi's design of experiments, we evaluated the wear behavior of nylon filled with calcium sulfate ($CaSO_4$) as a function of surface filler content, sliding speeds, and normal loads. The wear crack morphology was additionally determined, along with optimum conditions for the parameters of the tribological test using SEM microstructures.

47.2 Materials and Methods

Composites are typically composed of nylon polymers, combined with $CaSO_4$ nanoparticles as fillers to improve their bonding properties. Because of its superior surface polish and impact strength, nylon material composite is frequently used in industrial applications. $CaSO_4$ was added to Nylon at varied concentrations in this study to evaluate mechanical qualities such as tensile strength and hardness. During manufacture and testing, other characteristics (Table 47.1) such as load, sliding distance, and speed are taken into account. It is critical to initially analyze the key contributing parameter before archiving higher mechanical features. Taguchi's (L9) experimental concept and execution are depicted in Table 47.2. The Nylon/$CaSO_4$ hardness was measured using a composite Rockwell hardness test.

47.2.1 The Composites Fabrication

The first phase involved using a ME100LA mixer set to 190 °C with mixing blades spinning at 200 rpm to create NYLON/$CaSO_4$ composites in varying amounts over 20 min. The fundamental purpose of heating is to homogeneously and uniformly distribute the material throughout the mixture. The molten material is injected into

Table 47.1 Different levels of design factors

Factor	$CaSO_4$ (wt%)	Normal load (N)	Sliding speed (rpm)	Sliding distance (m)
Symbol	A	B	C	D
Level-1	4	10	100	500
Level-2	12	15	200	750
Level-3	20	20	300	1000

Table 47.2 Orthogonal array (L9) and control parameters

Treat	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Fig. 47.1 Tensometer for testing the specimens

the injection and molded under high pressure in the second step. The majority of the time, high pressure is employed to release internal stress. The material was gradually cooled once it had been set before being removed from the molding.

This tensometer model is identified as PC-2000 (Fig. 47.1), and it is used for tensile tests; specimens are indicated in Fig. 47.2, which is used to carry out tensile tests. Specimens were then tested for their wear properties. The materials' mechanical and wear properties were then evaluated by testing them under various normal load and speed situations. A Rockwell indenter was used to determine the hardness of the polymer composite. A scanning electron microscope was used to examine the material's fracture morphology (S-3000N Toshiba SEM). The wear rate was determined using an ASTM G99 wear monitor with a pin-on-disc type and 400 emery paper grade size.

47.3 Results and Discussions

47.3.1 Tensile Characteristics of Composites

According to the composites' characterization, $CaSO_4$ significantly affects the tensile strength of the material. The ultimate strength is peaks at 8%, and the tensile strength and strain values decrease with increase in filler percentage (Fig. 47.3). Tensile strength decreases with increasing filler content, meaning that less filler has better tensile properties.

Fig. 47.2 Tensile specimens of Nylon/$CaSO_4$

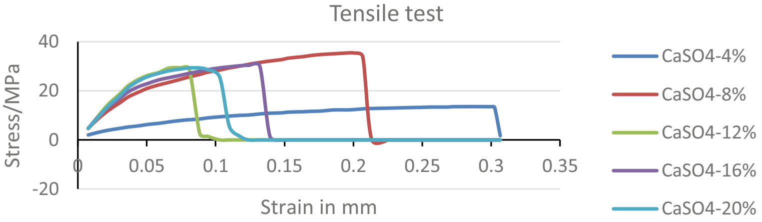

Fig. 47.3 Stress–strain curves of $CaSO_4$/Nylon polymer composites

47.3.2 *Effect of Filler Content on the Hardness*

Figure 47.4 depicts the change in hardness as the $CaSO_4$ filler amount increased from 4 to 12 wt% then decrease. The maximum hardness value for a $CaSO_4$ filler proportion of 12% is 100 HRM.

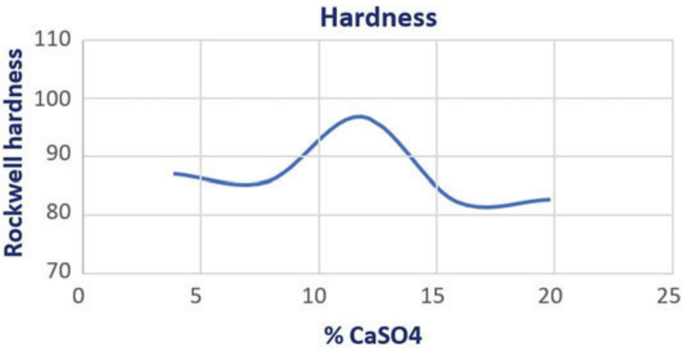

Fig. 47.4 Hardness is a function of $CaSO_4$

47.3.3 *Effect of Filler Content on Sliding Wear*

The wear rate of all the specimens was measured using the Taguchi orthogonal L9 array of trials. Figure 47.5 demonstrates that the wear rate increases as the filler content increases. In terms of weight %, $CaSO_4$ contributes far more than other input process ingredients. Speed has 73.41% of the overall contribution of the composite (Table 47.3).

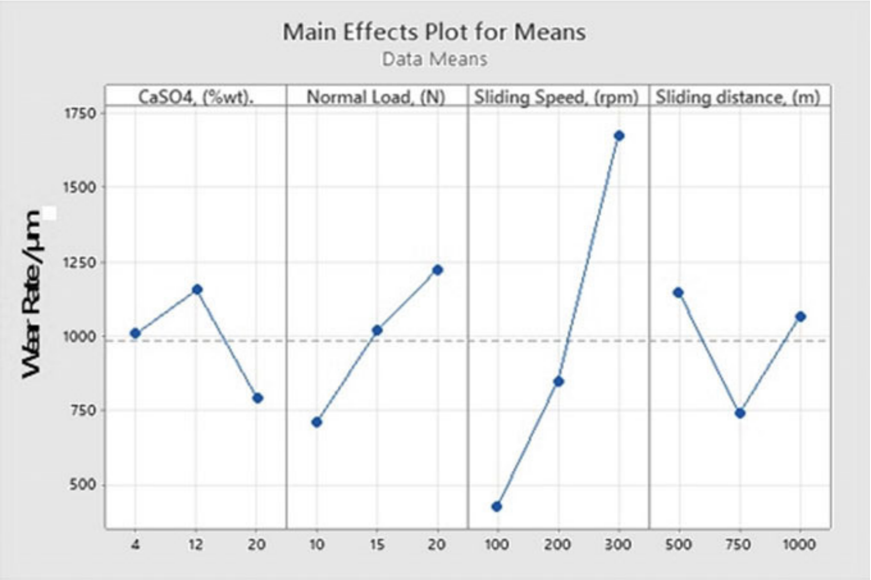

Fig. 47.5 Variation of wear rate

Table 47.3 ANOVA summary of the wear rate

Source	DF	Sum 1	Sum 2	Sum 3	Adj. SS	Adj. MS	*F*-value	*P*-value	Percentage contribution (%)
$CaSO_4$ (wt%)	2	1008	1155	792.7	199,263	99,631	0.19	0.829	6.07
Load (N)	2	713.3	1018	1224.3	396,516	198,258	0.41	0.68	12.07
Speed (rpm)	2	429.3	850.7	1675.7	2,411,494	1,205,747	8.28	0.019	73.41
Sliding distance (m)	2	1147	741	1067.7	277,841	138,920	0.28	0.767	8.46
Error	8				3,285,114				100

DOF degree of freedom, *SS* the sum of squares, *MSS* means of squares

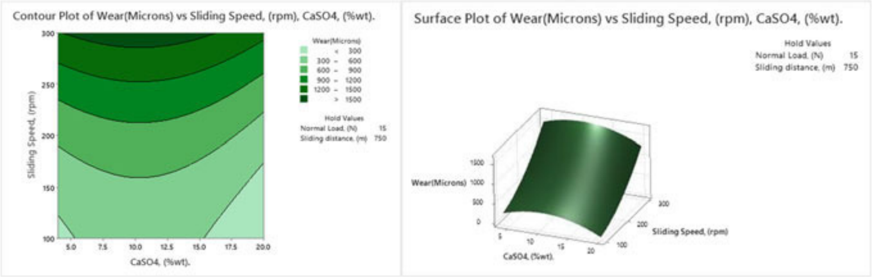

Fig. 47.6 Counter and surface plot of wear versus speed and $CaSO_4$

Table 47.4 Optimum process parameter to maximize and minimize the wear

	$CaSO_4$ (wt%)	Load (N)	Speed (rpm)	Sliding distance (m)
Maximum wear (μ)	12	20	300	500
Minimum wear (μ)	20	10	100	750

When the load is raised from 10 to 20 N, the wear rate decreases, and the load contributes 12.07% to the overall wear rate. Similarly, when the $CaSO_4$ wt% increased, the wear rate climbed until it reached 12%, and then it decreased. $CaSO_4$ is the influential factor, accounting for 28.26% of the total contribution. Major influencing factors counter and surface plots were developed for load and filler material (Fig. 47.6; Table 47.4).

47.4 Surface Morphology of the Composites

SEM images were taken for each Taguchi L9 array experiment, which altered the load, composition, and speed. All of the photos were shot at a magnification of 20 μm. The sample filler content remained constant from tests 1–3, however, the load increased progressively and the severity of microcracks decreased. At trail 1 start-up circumstances, the worn surface exhibits tiny grooves for tests 1, 2, and 3 with 4% $CaSO_4$ nanoparticles (Fig. 47.7). There is less distortion as the load increases. The microcracks discovered on trails 5, 6, and 7 with 12% $CaSO_4$ microparticles were almost identical, but the worn surface is homogeneous and intense (Fig. 47.8). Due to an increase in the $CaSO_4$ filler material content, particle clustering was found in the specimens for trials 7, 8, and 9 with 20% $CaSO_4$ nanoparticles (Fig. 47.9).

This study collects the wear debris generated during the wear tests Figs. 47.10, 47.11, and 47.12. The size of flakes or platelets becomes larger as the load and sliding distance increases.

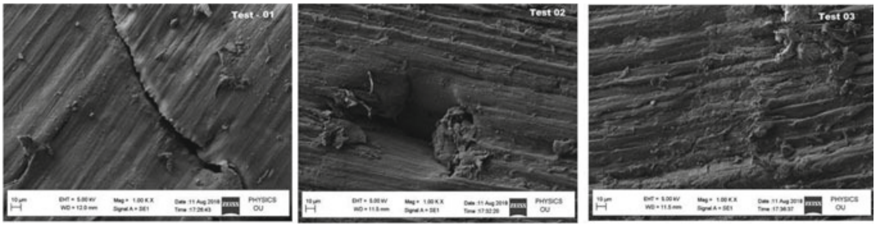

Fig. 47.7 Worn surfaces of specimens or trial conditions of 1, 2, and 3

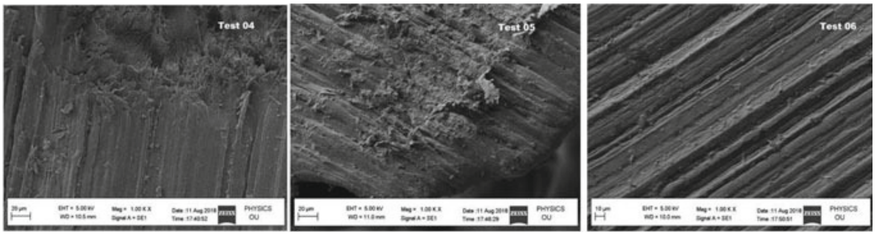

Fig. 47.8 Worn surfaces of specimens for trial conditions of 4, 5, and 6

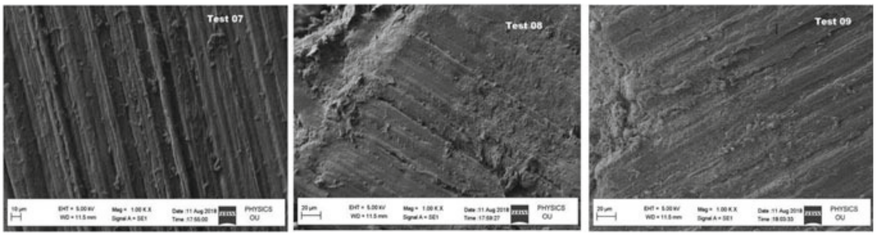

Fig. 47.9 Worn surfaces of specimens for trial conditions of 7, 8, and 9

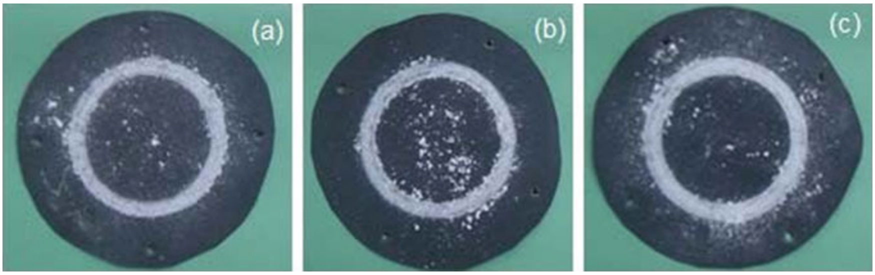

Fig. 47.10 Debris of specimens for trial conditions of 1, 2, and 3

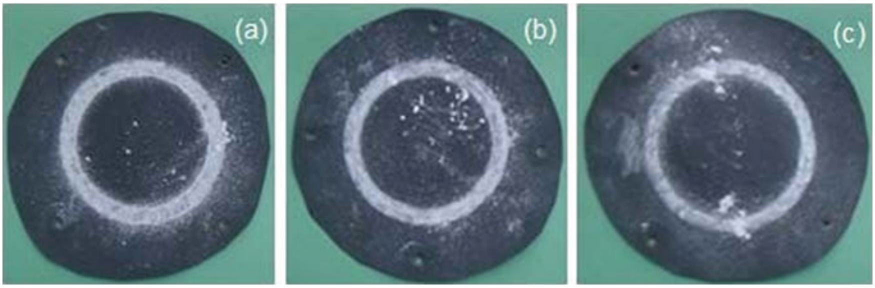

Fig. 47.11 Debris of specimens for trial conditions of 1, 2, and 3

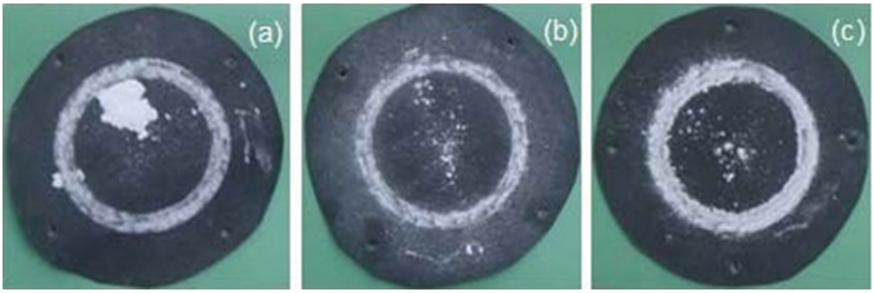

Fig. 47.12 Debris of specimens for trial conditions of 1, 2, and 3

47.5 Conclusion

A Nylon composite incorporating $CaSO_4$ particles was created using an injection molding method. Hardness, tensile strength, and wear rate have all been found to be affected by filler content. As the composite's filler content grows, so does its toughness and modulus of resilience. Filler content was increased from 4 to 12 wt%, which resulted in an increase in hardness. However, when the filler content was increased from 12 to 20%, the hardness decreased. The speed in the input process contributes more (73.41%) than the other input process components. The SEM picture clearly shows that as the stress increases, the worn surface cracks expand. The particle clumping on the surface becomes increasingly visible as the magnification rises. Future research may assist in developing the best composite material using dynamic mechanical analysis and temperature effects of this Nylon/$CaSO_4$ material.

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