AN EXPERIMENTAL INVESTIGATION OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF NYLON-$CASO_4$ POLYMER COMPOSITES USING TAGUCHI TECHNIQUES

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Abstract: The study uses Nylon matrix material with Calcium Sulphate ($CaSO_4$) as a filler material. An injection molding machine is used to make the composites. Taguchi L9 design of experiments are 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 during SEM for better findings. Among the major contributions of this paper is a decrease in ultimate strength due to increased composition of Calcium Sulphate in the composites as well as a variation in wear rate of 73.41% due to the sliding speed.

Keywords: Nylon, Tensile Strength, Pin-On-Disc, SEM, Taguchi

1 Introduction:

Polymer composites are commonly used in the manufacturing of industrial hardware. The majorities of composites utilized have strong mechanical and tribological qualities, are lightweight, and have high ecological and synthetic resilience semi-glass-like thermoplastic, nylon 6 is well-known in most companies due to its high quality, uniqueness, and substance resistance. It's widely used in modern airplanes, cars, machines, and other commercial applications where creep resistance, durability, and solidity are essential. Coordination of inorganic particle fillers has shown to be a viable strategy for increasing mechanical properties, particularly Nylon 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]. In a wear test of a nanosized silicon (SiO_2) and nylon polymer composite, SE images showed that the addition of 2% silicone reduced friction from 0.5 to 0.18 in comparison with pure nylon [2]. An ABS-AI polymer composite is prepared using different weight percentages and tested for mechanical and tribological properties. Comparing composites to pure ABS, it is found that composites have lower hardness and electrical resistance [3] Graphite filler is used as a filler for thrust washers and sleeve bearings made from Nylon 6/Teflon matrix [4]. Short fiber reinforced thermoplastic composites is 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. Polymeric such as Nylon-66, exhibit considerable benefits when combined with a proper percentage of nanoparticles as filler materials, such as Sic [6], Al_2O_3 [7], γ-Fe_2O_3 [8) and employed with other polymers composites. Compared to vinyl ester composites filled with chemosphere, microparticles and submicron particles provide superior mechanical and wear resistance. The submicron-sized particles are more successful in improving the wear opposition than the micro-sized particles [9]. The tribological performance of short fiber-reinforced polymers (SFRPs) can be improved by using nanoparticles because of their ability to reduce grating, especially when they are stacked in a silly way[10]. To produce untreated and surface-treated TiO_2, e-caprolactam is polymerized by anionic ring-opening polymerization utilizing turning molding. The melting temperature, average molecular weight, water observation, and conversion degree all decrease compared to the actual value [11]. According to this review, nylon 6 is one of the best available polymers for matrix in a polymer composite material. The filler materials have a significant impact on the mechanical properties of the composite. Even though much research is being conducted in the field of polyamide. It has also been found that graphite has a lower affinity for the PA6 matrix. To improve graphite's affinity for the PA6 matrix, more research should be done. [12]. The ultimate strength of composites has decreased with increasing boron nitride content due to the substantial dilatational component of ABS, which indicates a volume change. A flaw in ABS/BN polymer composites was that the filler agglomerates around areas of non-uniform mixing [13]. In the ABS/BN polymer composites, brittle cracking was shown by crack growth lines that moved in a radial direction. The average molecular weight of matrix nylon filled with nano-alumina changed slightly compared to micro-alumina. NA=MCN composites have greater Tg and storage moduli than nylon. Adding 3 wt.% nano-Al_2O_3 particles increased the tensile strength by 52%. NA=MCN composites with the same Al_2O_3 weight percentage had better thermal and tensile performances than MA=MCN composites[14]. Tensile strength is highest at 4% wt. Si3N4 and declines with more. The hardest Nylon-6/Si3N4 composite weighted 16 percent. Speed accelerated wear. The composites wear less (up to 4% wt Si3N4) than 12 and 20% wt Si3N4. SEM images show that most of the nanoparticle variation comes from the matrix. SEM images assist in comprehending composite surfaces at different inputs [15].

According to Taguchi's design of experiments, we evaluated the wear behavior of nylon filled with calcium sulfate ($CaSO_4$) at varying surface filler content, sliding speeds, and normal loads. Through the use of SEM microstructures, we also determined the morphology of wear cracks, along with the optimal conditions for a Tribological test.

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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. It is important to take into consideration other characteristics (Table-1) during manufacture and testing, including sliding speed, load, and speed. It is critical to initially analyze the key contributing parameter before archiving higher mechanical features. Taguchi's (L9) experimental concept and execution are depicted inTable2. Nylon/$CaSO_4$ hardness was measured using an ac composite Rockwell hardness test.

Table 1. Design factors at different levels.

Factor	$CaSO_4$, (%wt).	Normal Load,(N)	Sliding Speed,(rpm)	Sliding distanc,(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 2. Control parameters and orthogonal array(L9)

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

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 / $CaSO_4$ composite in varying amounts over 20 minutes. The fundamental purpose of heating is to homogeneously and uniformly distribute the material throughout the mixture. The molten material is injected into

Figure 1. Tensometer for specimen testing

the injection and molded under insistent in the second step. When it comes to releasing internal stress, high pressure is frequently used. After it had set, the material is gradually cooled before being removed from the mold.

Figure 2: Tensile specimens of Nylon/$CaSO_4$

The Tensometer model is identified as PC-2000 (fig.1) and it is used for tensile tests; The specimens to be tested for tensile strength are shown in figure 2. Material's mechanical and wear properties were evaluated under various normal load and speed conditions after specimens were tested for their wear properties. Rockwell indenter was used to determine the hardness of the polymer composite. To examine the fracture morphology of the material, an electron microscope was used (S-3000N Toshiba SEM). Wear rate was determined using an ASTMG99 wear monitor with a pin-on-disc type and 400 emery paper grade.

3. RESULTS & DISCUSSION:

3.1 Tensile characteristics of composites

The material's tensile strength is significantly impacted by $CaSO_4$, according to the composites' characterization the ultimate strength peaks at 8%, and the tensile strength and strain values reduce as the filler percentage increases (Figure 3). Tensile strength decreases with increasing filler content, meaning that less filler has better tensile properties.

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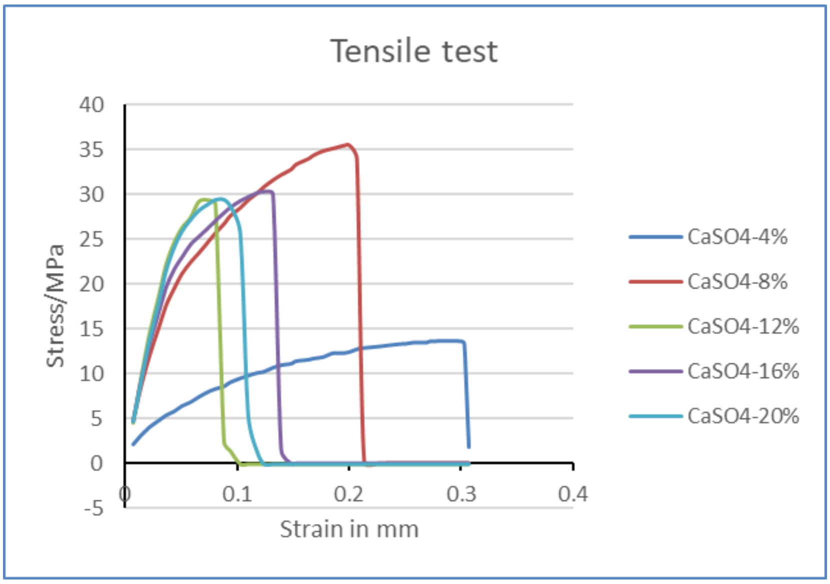

Figure 3. Stress-strain curves of $CaSO_4$/Nylon polymer composites.

3.2 Influence of filler content on hardness.

Figure 4 depicts the change in hardness as the $CaSO_4$ filler amount increased from 4% to12%wt then decrease which increased hardness. However, In the case of an increase in filler content from 12% to 20% the hardness decreased The maximum hardness value for a $CaSO_4$ filler proportion of 12%wt is 100 HRM.

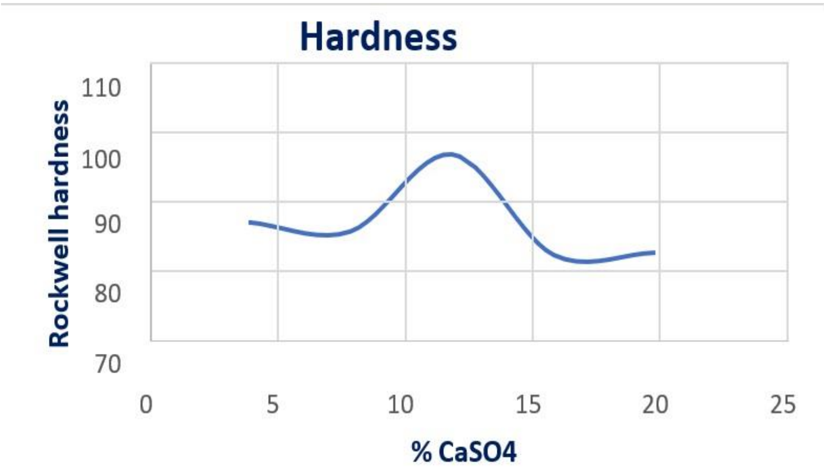

Figure 4. Hardness is a function of $CaSO_4$

3.3 Impact of filler concentration on sliding wear

The Taguchi orthogonal L9 array was used to measure the wear rate of the samples. Figure 5 demonstrates that the wear rate increases as the filler content increases. In terms of weight %, $CaSO_4$contributes far more than other input processing ingredients Speed has 73.41% of the overall contribution of the composite (Table 3).

Table 3: ANOVA Summary of the Wear Rate

Source	DOF	Sum1	Sum2	Sum3	Adj SS	Adj MS	F-Value	P-Value	% contribution
$CaSO_4$(% Wt.)	2	1008	1155	792.7	199263	99631	0.19	0.829	6.07%
Load (N)	2	713.3	1018	1224.3	396516	198258	0.41	0.68	12.07%
Speed(Rpm)	2	429.3	850.7	1675.7	2411494	1205747	8.28	0.019	73.41%
Slidingdistance,(m)	2	1147	741	1067.7	277841	138920	0.28	0.767	8.46%
Error	8				3285114				100%

(DOF; Degree of freedom, SS: the sum of squares, MSS: means of squares)

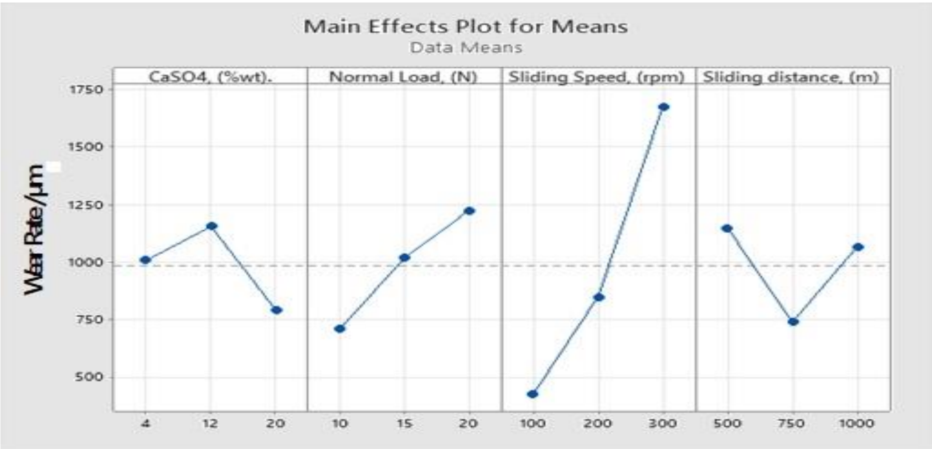

Figure 5: Variation of wear rate

When the load is raised from 10 to 20N, the wear rate decreases and the load contributes12.07 percent to the overall wear rate. Similarly, when the $CaSO_4$ percent Wt. increased, the wear rate climbed until it reached 12 percent, 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 developed for load and filler material (Figure 5).

Table 4. Wear-optimal process parameters.

	$CaSO_4$ (%wt)	Load(N)	Speed(rpm)	Slidingdistance,(m)
Maximum wear (microns)	12	20	300	500
Minimum wear (microns)	20	10	100	750

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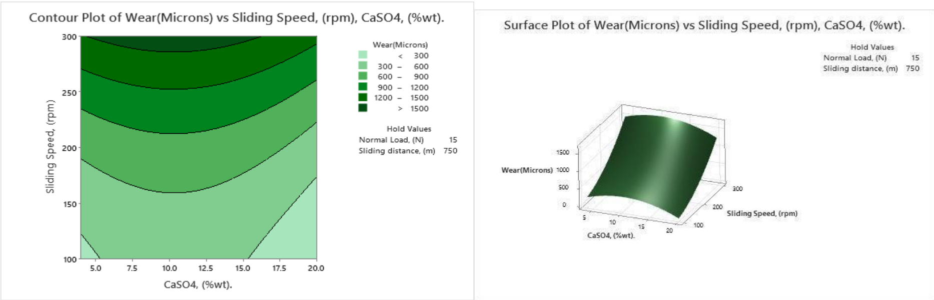

Figure 6: counter and surface plot of wear vs speed/CaSO4

4. Morphology of composite surfaces:

With each Taguchi L_9 array experiment, SEM was used to change load, composition, and speed. The photographs were all taken at a magnification of 20 micrometers. The sample filler content remained constant from tests 1 to 3, however, the load increased progressively and the severity of micro-cracks decreased. At trail1start-up circumstances, the worn surface exhibits tiny grooves for tests 1, 2, and 3 with 4%wt $CaSO_4$ nanoparticles (Figure 7). There is less distortion as the load increases. The micro-cracks discovered on trails 5, 6, and 7 with 12% $CaSO_4$ microparticles were almost identical, but the worn surface is homogeneous and intense. (Figure 8). Higher content of $CaSO_4$ filler material led to particle clustering in trials 7, 8, and 9 with 20% $CaSO_4$ microparticles (Figure 9).

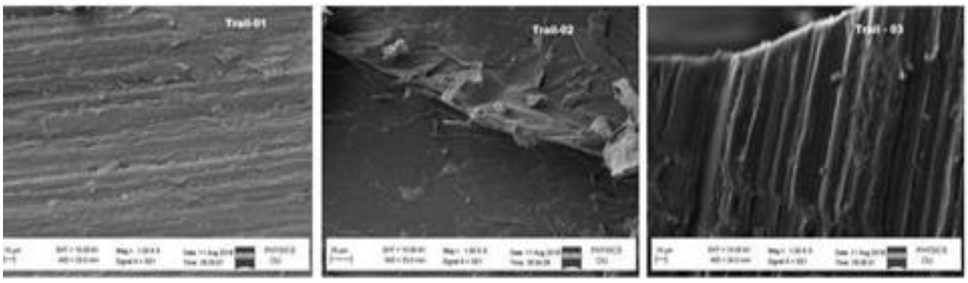

Figure 7. Worn surfaces of specimens or trial Conditions of 1, 2, and 3.

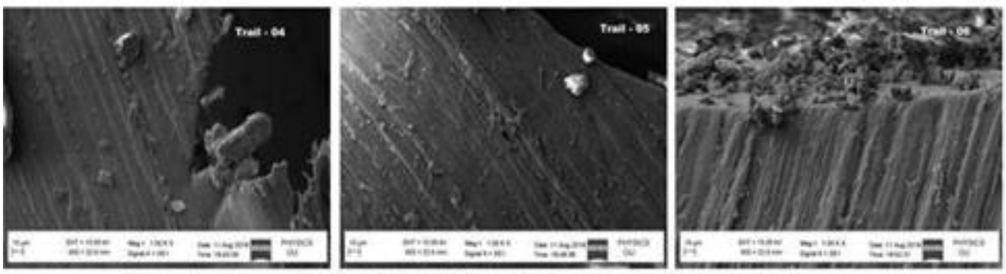

Figure 8. Worn surfaces of specimens for trial conditions of 4, 5, and 6.

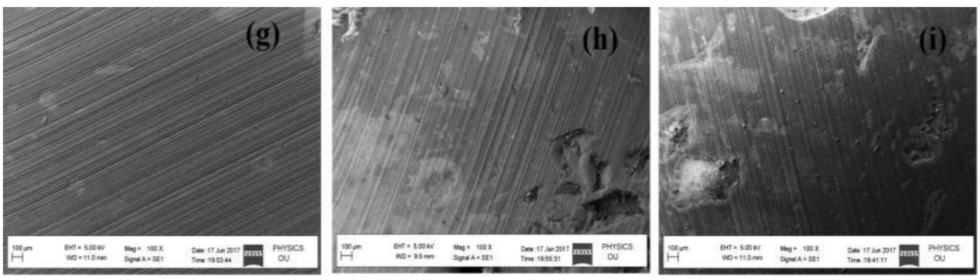

Figure 9. Worn surfaces of specimens for trial conditions of 7, 8, and 9.

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This study collects the wear debris generated during the wear tests Fig.10, 11, and 12. The size of flakes or platelets becomes larger as the load and sliding distance increase.

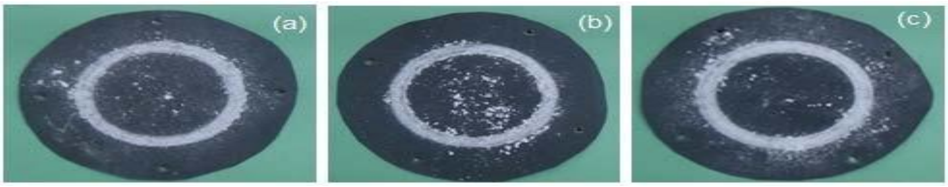

Figure 10. Debris of specimens for trial conditions 1, 2 and 3

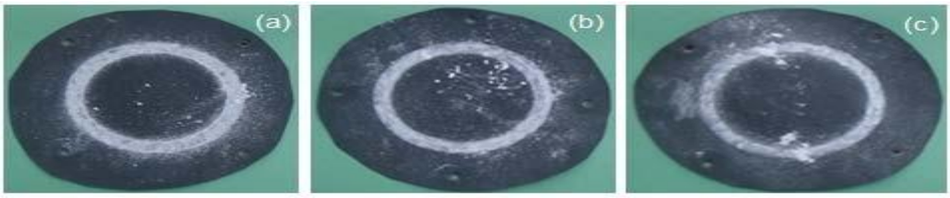

Figure 11. Debris of specimens for trial conditions 1, 2 and 3

Figure 12. Debris of specimens for trial conditions 1, 2, and 3.

5. Conclusion:

Tensile strength increased at 8% $CaSO_4$ and declined at 20% $CaSO_4$. As a result, the composite filler content affected the composite's toughness and modulus of elasticity. On increasing the filler % contents of $CaSO_4$ the Rockwell hardness is observed to be maximum at 12%BN. According to Taguchi's design of experiments, Nylon composites filled with micro-sized $CaSO_4$ were subjected to wear tests for varying filler content, normal load, sliding distance, and speed. There is a greater contribution from the speed of the input process (73.41%) than from the other components of the input process .it can be seen in the SEM picture that the worn surface cracks expand as the stress increases. 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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