An investigation of mechanical and sliding wear behavior of ABS/Si_3N_4 nanoparticles fabricated by an injection molding

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ABSTRACT

Keywords:
ABS,
Nano Si_3N_4,
Tensile,
Hardness,
Wear,
SEM.

In this research work, the Polymer composites of Acrylonitrile - Butadiene - Styrene (ABS) and filler material of Si_3N_4 nanoparticles made using an injection molding machine by varying filler content of Si_3N_4. During the tensile test, it observed that the tensile characteristics of the composite enhanced by adding Si_3N_4 nanoparticles and also observed that hardness of the composite enhanced during the Vickers microhardness test. During the study of scanning electron microscopic analysis, It observes that the fracture surface on the specimen after tensile and wear tests. Wear properties of the composite are evaluated using different filler content, load conditions, speed, and sliding distances. Wear properties of the composite are mainly affected by load conditions and sliding distance.

1. Introduction

Polymer materials extensively applied in a lot of applications due to their superior characteristics. Polymer composites often used as a replacement for metal-based composites in mechanical sectors. They also used in automotive accessories, polymer gears, and contemporary car bodies, and badminton ratchets, etc. Modern methods are developing to improve the properties by adding the nanoparticles to the composite materials, which result in the enhancement of properties such as mechanical strength, stiffness, hardness, etc.

Divakar et al. [1] explain that the properties are enhanced with the addition of ABS with the double layer glass fiber also increases the peak load. [2, 3] states that the improvement of tribological properties and the effect of material wear with the addition of the nanoparticles. Sudeepan et al. [4], during the study of specimens using the Taguchi method for ABS / $CaCO_3$ polymer composites, found that there is variation in the mechanical properties with various compositions and the filler materials. Nylon 6/Teflon as a matrix material and graphite as a filler material for the development of sleeve bearing and thrust washer [5]. The mechanical properties such as tensile strength and the wear properties of composite materials were studied for various filler materials such as Al_2O_3, Graphite, Okra Fiber and found that increment in the mechanical properties [6][7]. A.C Reddy [8] studied the influence of matrix alloy and Si_3N_4 nanoparticles on wear characteristics of aluminum alloy composites. The highest wear rate is observed for vinyl ester composites under dry sliding conditions at a normal applied load of 10N, sliding speed of 1.9 m/s, and particle size of 2l m. K S Kumar and A.C Reddy [9] explained that BN to Nylon 6 matrix increases the tensile strength and the hardness while it reduces the ductility of the Nylon/BN polymer composites. [10] Explained that wear parameters such as the wear loss, the specific wear loss, and the COF, characterizing the wear resistance influenced by nanocomposites. [11,12] investigated tribological characteristics of ABS thermoplastic composites for graphite and nanocarbon materials. Flexural properties of ABS-copper in the injection molding method for FDM Feedstock were studied by Nasuha et al. [13] and found that higher wear resistance for the addition of nanoparticles for various proportions of nanoparticles. Isa et al. [14] investigated the characteristics of copper filled ABS composite for freeform fabrication. Analysis of structural components and surface morphology of palm fiber reinforced ABS composites continued presented by Gudrun Neher et al. [15]. Discuss of mechanical behavior, and tribological

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of cenosphere filled vinyl ester composites using the Taguchi method studied by SR Chauhan and Sunil Thakur [16] and results concluded that adding the filler materials can improve the properties.

It can be concluded from the references that there is a further study on the tribological and mechanical properties of ABS/Si_3N_4 composites. In this present investigation, ABS thermoplastic was chosen as matrix material due to the full range of applications in aircraft and automobiles. Nano-sized Si_3N_4 selected as the filler material. ANOVA- Analysis of variance is carried out to study the level of significance of factors and their connections on the overall grey relational position. Finally, the wear conduct of polymer composites examined with the assistance of (SEM) scanning electron microscopy pictures.

2. Experimental Details

2.1 Materials and preparations of specimens

The filler material selected for this work was silicon nitride (Si_3N_4) with a particle size of nearly 100 nm. The matrix chosen is acrylonitrile-butadiene-styrene (ABS). The melting point of ABS used was 230 °C, and its melt flow index was 12 g per 10 min. For the preparation of specimens, the filler material weighed in proportions of 4, 8, 12, 16, and 20% wt of Si_3N_4 was added to the ABS polymer matrix. These Si_3N_4 nanoparticles were blended with ABS in a ME100LA blender at a temperature of 190°C. The blending time was 20 min, and the speed of mixing blades was 200 rpm. The injection molding machine was utilized to prepare the ABS/ Si_3N_4 polymer nanocomposite specimens. The blend of ABS and Si_3N_4 nanoparticles was heated in the barrel to make it soft and molten. The combination of ABS and Si_3N_4 nanoparticles then constrained under strain inside a forming cavity where it was exposed to holding the weight for a particular time to adjust for material shrinkage. For all examples, the heating temperature of the charging barrel-25°C, injection pressure-70 MPa, and the cooling time of moldings were kept consistent. The material starts to set as the mold temperature decreases under the glass progress temperature (105 °C) of ABS. After an adequate time, the material was solidified into the mold shape and got ejected.

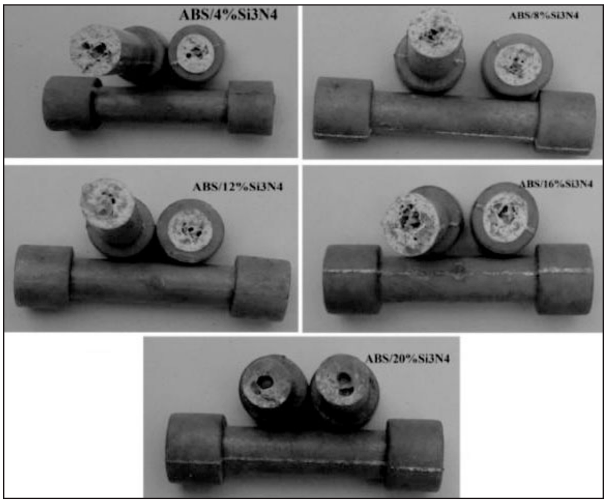

Fig. 1. Tensile specimens of ABS/ Si_3N_4.

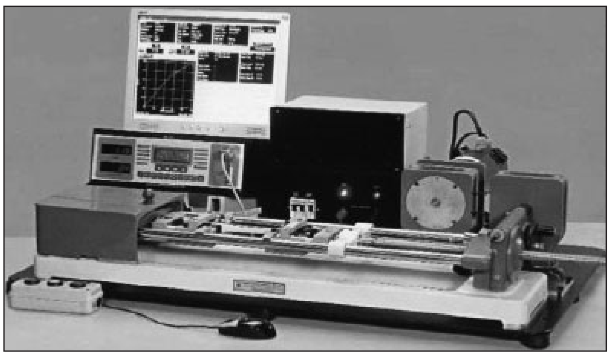

Fig. 2. Tensometer.

2.2 Mechanical test

Fig.1 shows the tensile specimens of ABS/ Si_3N_4. Tensile tests were performed on the Tensometer Model PC-2000 (Fig. 2). Microstructures were seen under a scanning electron microscope to evaluate the crack surfaces of tensile tests at room temperature. The mechanical tests performed for each sample with each composition and the results were recorded. Microhardness testing of composites was carried out in UHL microhardness tester with Vickers diamond indenter at an indentation load of 100gf. The microhardness tester was controlled through a touchscreen-based system, and hardness numbers are noted. At least two hardness values for each example were reported.

2.3 Design of experiments

The determination of design parameters was the essential stage of the design of experiments. The design factors were sliding speed, normal load, filler content, and sliding distance. Based on the literature review, the filler content (4, 12, and 20 %wt), normal load (10, 15 and 20N), sliding speed (100, 200 and 300 rpm) and sliding distance

Table 1
Design factors with different levels.

Factor	Symbol	Level 1	Level 2	Level 3
BN, %wt.	A	4	12	20
Normal Load, N	B	10	15	20
Sliding Speed, rpm	C	100	200	300
Sliding distance, m	D	500	750	1000

(500,750 and 1000m) are selected as design parameters and are shown in Table.1 speed wear tests were conducted as per Taguchi's design of experiments. The levels considered for the process parameters are tabulated in Table 2. Wear experiments are carried using the orthogonal array, L9. Vickers microhardness was conducted for ABS/ Si_3N_4 polymer composites. The analysis is carried out with a scanning electron microscope to find the consequence of wear tests of ABS/ Si_3N_4 polymers composites.

3. Results and Discussion

Tensile tests of ABS/ Si_3N_4 polymers nanocomposites specimens with different compositions of Si_3N_4 (0, 4, 8, 12, 16, and 20 wt %) were conducted, and the results of load and displacement curves are exhibited in Figure 3(a) to 3(f). It was noticed that tensile property increases by adding Si_3N_4 up to 8 %wt reaches maximum, as shown in fig 3(c), and then decreases.

Table 2
Orthogonal array (L9) and control parameters.

Treat No.	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

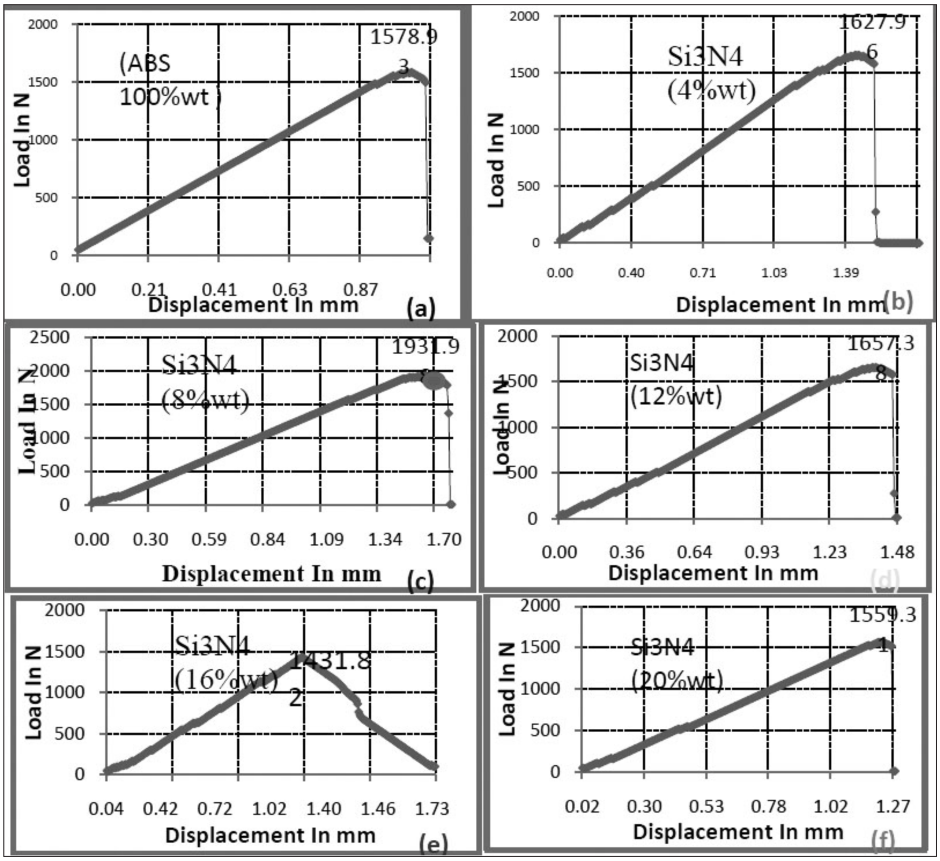

Fig. 3. Effects of Load and displacement of ABS/ Si_3N_4.

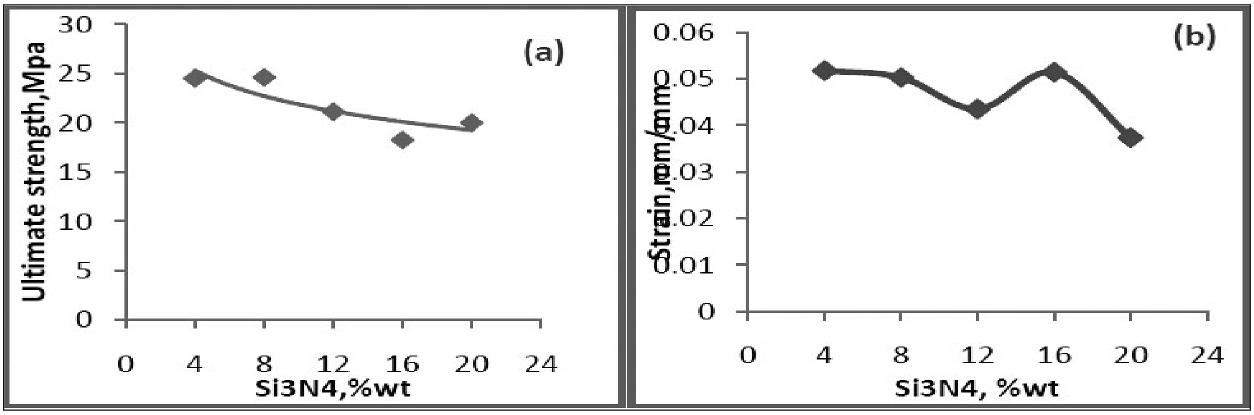

Fig. 4. As a function of Si_3N_4, Ultimate strength (a) and corresponding strain (b).

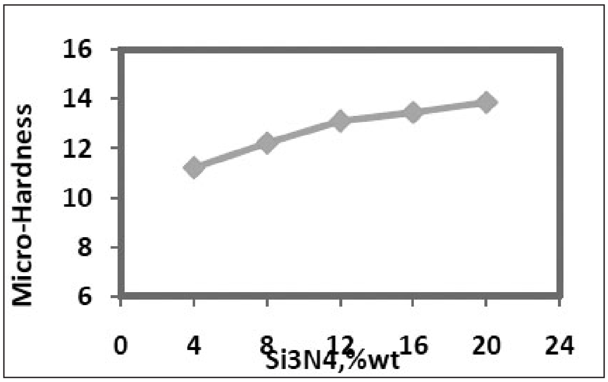

Fig. 5. Effect of Vickers micro-hardness of ABS/ Si_3N_4.

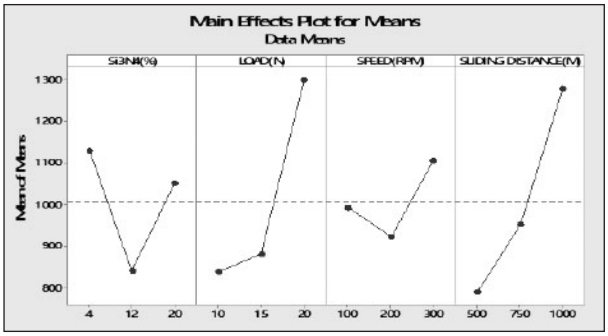

Fig. 6. Wear rate variation with (a) weight fraction of BN and (b) Normal load (N).
(c) Speed (RPM) (d) Sliding distance (M).

Table 3
ANOVA (before pooling) summary of the wear rate.

Parameter	Sum1	Sum 2	Sum 3	SS	v	V	P
Si_3N_4 (Wt %)	3389.1	2526.9	3153.9	132378	2	66189	14.1
Normal load(N)	2523	2646	3900.9	387671	2	193835	41.2
Sliding Speed(Rpm)	2978.1	2774.1	3318	50350	2	25175	5.4
Sliding Distance(m)	2373	2862	3834.9	369255	2	184627	39.3
Error	0	0	0	0.0	1	0	0.00
T	11263.2	10809	14207.7	939654	9	469826	100.00

From fig. 4(a), there is a decrease in ultimate strength with increment in %wt of silicon nitride (Si_3N_4). With an increase in 4%wt to 8%wt of Si_3N_4 does not impact the ultimate tensile behavior of ABS/Si_3N_4 polymer composites. The ultimate strength of ABS/16%wt Si_3N_4 polymer nanocomposite is different from other compositions.

In the fig. 4(b), the strain at an ultimate tensile strength of ABS/16%wt Si_3N_4 polymer composite is higher than the strain of other polymer nano compositions. The impact of ABS/Si_3N_4 polymer nanocomposites on hardness examined in this investigation. From Fig. 5, it observed that the hardness of the composites was recorded using Vickers's micro-hardness test. The Si_3N_4 filler materials increase the hardness of ABS in increasing order. Subsequently, the micro-hardness also increases with increment in the filler content.

From figure 6, it observes that the wear rate is highest for 4%wt Si_3N_4 and lowest for 12%wt Si_3N_4. With an increase in the normal

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Sliding Distance(m)	2373	2862	3834.9	369255	2	184627	37.3
Error	0	0	0	0.0	1	0	0.00
Pooled error	2978.1	2774.1	3318	50350	2	25175	5.1
T	14241.3	13583.1	17525.7	990004	9	469826	100.00

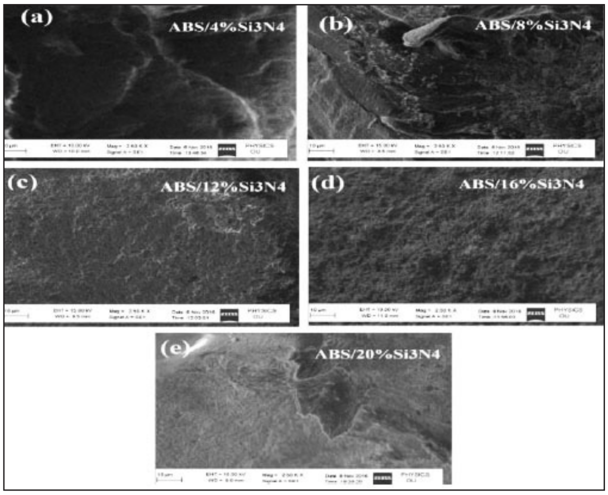

Fig. 7. Fractography of ABS/ Si_3N_4 polymer composites.

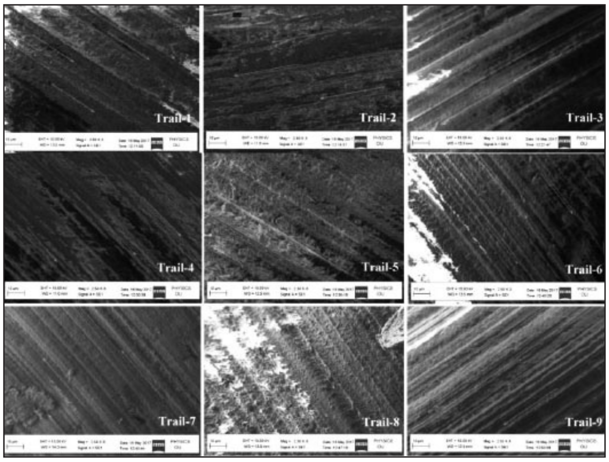

Fig. 8. Trial conditions of worn surfaces specimens.

applied load, there is an increase in the wear rate. Wear rate is maximum at the load of 20N at speed 300 rpm. As the sliding distance increases from 500m to 1000m, wear rate increases to the maximum. Table 3 describes the analysis of variance (ANOVA) for the experiment. Percentage contribution is estimated using the ANOVA test to determine the influence of the process parameters. Table 4 describes the ANOVA after pooling, which confirms that normal load and sliding distance with contributions 39.2% and 37.3% respectively are the most significant factors affecting the wear rate of ABS/ Si_3N_4 composites.

Morphological analysis of ABS/ Si_3N_4 composites determines the adhesion between Si_3N_4 and ABS composite, the source of failure, and the correlation with mechanical input. Scanning electron micrographs for varying wt (percent) of filler in ABS/ Si_3N_4 composites were expressed in pictures 7(a)-7(e) at a magnification of 2.50 X. It observes that the polymer structure is tough for 4% & 8%wt Si_3N_4 in the micrographs 7(a) and 7(b). The proportion of linear voids has improved. The micrograph with 12%wt filler was expressed in Figure 7(c) indicates that the composite surface was extremely soft. It also is shown that the interfacial adhesions between the filler and matrix. The micrographs 7(d) and 7(e), respectively of 16% and 20%wt filler, indicate that the composite surface is rough. With a rise in the filler content of the composite, the number of voids decreased, the region of each void is also enhanced.

The SEM pictures for abrasive wear analysis of ABS/Si_3N_4 composite samples shown in Figure 8. Worn surfaces with complete plowing paths, many microcracks, and scratched surfaces filled with distinct wear debris observed. These grooves are perpendicular to the path of slipping. Although nanocomposites are improved for 4 wt% Si_3N_4. Figure 8 (Trial-5) shows that there was a comparatively simple layer with no microcrack on the surface when 12 wt% Si_3N_4 nanocomposite was used. This might be due to the homogeneous

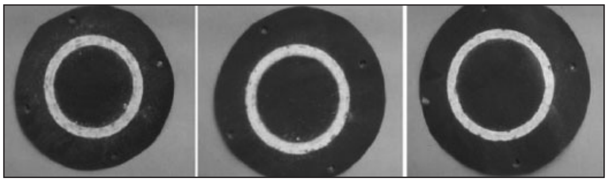

Fig. 9. Debris of specimens for trial conditions of 1, 2, and 3.

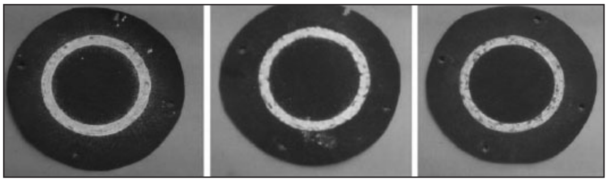

Fig. 10. Debris of specimens for trial conditions of 4, 5, and 6.

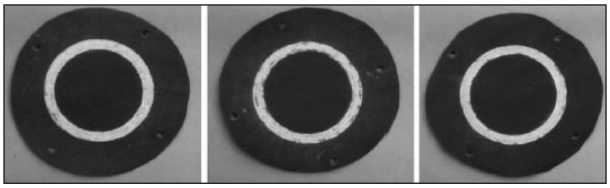

Fig. 11. Debris of specimens for trial conditions of 7, 8, and 9.

distribution of Si_3N_4 within the polymer matrix. In the case of 12 %wt Si_3N_4-filled nanocomposites. This was observed less wear rate. However, higher abrasive wear was found in 20 wt% Si_3N_4 strengthened samples. These findings suggest that Si_3N_4 nanoparticles decrease abrasive wear that can be seen numerically.

The wear debris produced during the wear tests were collected from figures 9, 10, and 11. With an increase in applied load and sliding distance, the sizes of the platelets or flakes were increased, and their quantity also increased.

4. Conclusions

The present study is carried out for investigating the influence of Silicon Nitride nanoparticles on the mechanical and tribological properties of ABS polymer composites. Tests have been conducted for tensile behavior, hardness, and wear behavior of the composites, and the following conclusions are given below.

- The addition of Si_3N_4 nanoparticles showed an increase in the tensile strength of ABS/ Si_3N_4 composites.
- The hardness of the polymer composites is increasing with the increase in filler content of Si_3N_4.
- Normal load and sliding distance are the most significant factors affecting the wear rate of ABS/Si_3N_4 composites.
- The composites filled with Si_3N_4 nanoparticles showed lower wear rates at the combination of 12% wt Si_3N_4, 10N load, 200 rpm speed, and 500 m sliding distance.
- The surface of the composite becomes rougher with the increase of the filler content in the composite.

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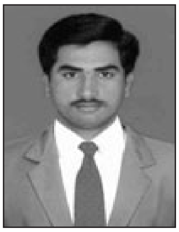

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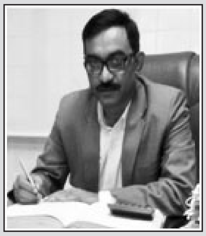

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