

## RESEARCH ARTICLE



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## Characterization of mechanical and wear properties of ABS/SiO<sub>2</sub> nanoparticles

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### Abstract

**Objective:** In this present work, the SiO<sub>2</sub> nanoparticles as filler materials and ABS as a matrix material taken for the injection molding process to prepare the specimens, after that, to study the enhancement of mechanical properties and wear performance of composite materials. **Method/Findings:** SiO<sub>2</sub> nano particles are added to Acrylonitrile Butadiene styrene (ABS) polymer composites at various weight fractions. It is also found that tensile strength, hardness, and wear properties improved in reinforcement. A pin-on-disc type friction and wear monitor (ASTM G99) was employed to evaluate wear behavior of ABS/SiO<sub>2</sub> polymer composites. In this experimental study, the input process parameters such as load, sliding distance, and speed are considered and optimized for the composite materials' properties. Tensile tests and wear tests were conducted to examine, and the properties of the material were studied. Morphology of the fractured material was studied using SEM analysis. The wear debris observed to explore the flacks and groves of the content during wear test for this study Orthogonal array (L9) and control parameters. **Applications/Improvements :** The significant contributions of this work are the decrease of ultimate strength with increasing content of SiO<sub>2</sub> in the composites, and the sliding speed converted to 45.51% of the wear rate variation. Mechanical and wear properties of ABS/SiO<sub>2</sub> nanoparticles polymer composites were studied further.

**Keywords:** ABS; SiO<sub>2</sub> Nanoparticles; tensile; hardness; wear; SEM

### 1 Introduction

Acrylonitrile butadiene styrene (ABS) is a thermoplastic polymer. The most important mechanical properties of ABS are impact resistance and toughness. The mechanical properties of thermoplastic polymers can be further improved with the addition of metallic fillers. Because of its good shock absorbance, ABS is used for golf club heads, automotive trim components, and automotive bumper bars. ABS is easily injection molded and machined. Nanoscale fillers are better than micro-size fillers due to an increase in surface area. To improve the wear resistance. The optimum strength of the

composite material with ABS nanoparticles was achieved with 7% and 24%. As there is a continuous increase in elastic modulus, the clustering problem would lower the material's tensile strength. The content slowly changes from ductile to brittle due to the incorporation of nanoparticles in the composite<sup>(1)</sup>. The addition of SiO<sub>2</sub> particles increased the strength of the epoxy. Tensile strength is maximum when the percentage of the SiO<sub>2</sub> is 3%<sup>(2)</sup>. Friction behavior and anti-wear abilities of the ABS polymer composite improves with the addition of a small number of graphite particles. Graphite enhances the wear resistance of ABS composite and reduces the wear and adhesive nature of the composite<sup>(3) (4)</sup>.

Tensile and flexural modulus of the composites strengthened by the addition of the ZnO filler material up to a certain extent, and later there is a decrease in tensile strength. Hardness value increases with an increase in filler content<sup>(5)</sup>. Inorganic filler material shows the impact on the mechanical and tribological behavior of the material. When Short Basalt Fiber (SBF) filler material was used for ABS composite, there is a weaker interfacial bonding between composite and the filler material. With an increase in the percentage of SBF content, wear strength and surface hardness is enhanced, while the weakness of the interfacial bonding between fiber and composite leads to a decrease in the impact strength<sup>(6)</sup>. Teflon nanoparticles with Nylon 6 composite increased the tensile strength and reduced the ductility of the material. Fluorine particles of the Teflon form a bond with the composite<sup>(7) (8)</sup>. Increasing boron nitride content decreased the ultimate strength of the material. Due to the non-uniform mixing of ABS/BN composites, radial crack growth occurs, which leads to brittle cracking. On increasing the applied load, the wear rate has increased<sup>(9)</sup>. Nylon 66 composite material with CaCO<sub>3</sub> nanoparticles reduces elongation from 50% to 10%. As elongation decreases, there is an increase in the hardness<sup>(10) (11)</sup>. Si<sub>3</sub>N<sub>4</sub> increased the tensile strength of the material. At 16% wt. of Si<sub>3</sub>N<sub>4</sub>, Rockwell hardness number of the composite is higher than at other combinations<sup>(12)</sup>. For 1 wt. Percent rod-shaped Si<sub>3</sub>N<sub>4</sub> particles, significant enhancement in tensile properties was observed. The research FE-SEM shows that the particles formed by the rod can be effectively aligned in the direction of the extrusion<sup>(13)</sup>.

As mechanical properties, the tensile strength increase by 4% of BN, and decreases of BN / Nylon-6 composites to 16 percent of BN. Enhancing the Rockwell hardness is the highest filler value of percent BN 12 %wt<sup>(14)</sup>. The mechanical properties of bio-composites are determined by composite matrix, fiber volume fraction, epoxy dependent resin forms, and alkali concentration. The alkali treatment is used for Soybean, and canola-based resin significantly contributes to the composite's strong mechanical properties<sup>(15)</sup>. The chemically-treated hemp-banana-glass fiber hybrid laminates display the property for high tensile than two other combinations do. This has the most top tensile properties of 60.99 MPa, followed by the chemically treated glass-banana fiber hybrid laminates, which have a tensile property of 60.45 MPa<sup>(16)</sup>. Using the composites of nanoparticles are more strengthen than pure metals and improving mechanical and wear properties of the composites, the researches studied on the concepts of different composite materials, viz., Nano SiO<sub>2</sub>/PTFE<sup>(17)</sup>, ABS/SiO<sub>2</sub><sup>(18)</sup>, Graphene and Nano fillers<sup>(19)</sup>, Al-Si10-Mg alloy/sugarcane<sup>(20)</sup>.

Mechanical and wear behavior is the most essential properties of the polymer and its composites. Unfilled polymers could not satisfy the requirement wherein a combination of features such as excellent mechanical and tribological properties is required. The Wear test conduct filled with ABS and nano-sized SiO<sub>2</sub> composites for varying filler material have been investigated; Normal load, sliding speed, and sliding distance of three levels of each parameter were according to the experimental design by Taguchi. The structure of wear paths was also studied for the settings' initial and optimal conditions after the tribological tests were observed using SEM microstructures.

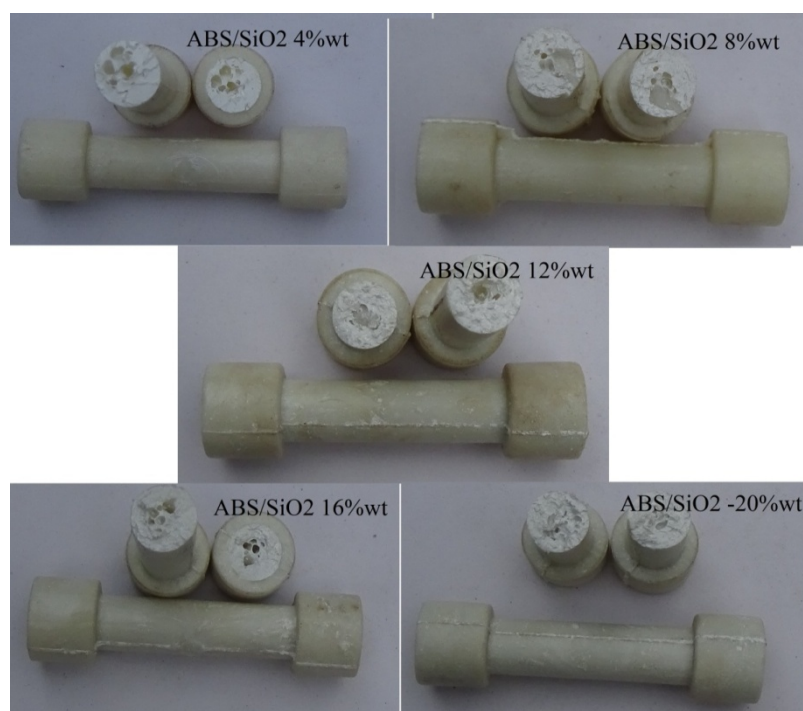
## 2 Materials and Methodology

The filler material is 100 nm of SiO<sub>2</sub> added to ABS composite material. SiO<sub>2</sub> was added by varying the proportions from 4% to 20 % by weight. The essential purpose of SiO<sub>2</sub> was to examine the effect of SiO<sub>2</sub> filler content in ABS material and to see the micro-crack hardness and wear behavior of composite. For this, ME 100LA mixer used to mix the SiO<sub>2</sub> nanoparticles with SiO<sub>2</sub> to maintain homogeneity. Material is heated to 190°C and stirred with a speed of 200 rpm for 20 min. This mixture is placed in the hopper and is heated to remove stress and compensate for material shrinkage. Material is heated to 190°C the melting point of 230°C, during the recrystallization phase, the void and imperfection in the content get removed as it holds for a specific time. The material was injected into the mold at 70 MPa. After setting time, the material ejected from the mold, and tensile and wear tests were carried out. To test the tensile strength of specimens using the Tensometer Model, PC-2000 ( Figure 2 ) was used. The test specimens were selected as per the Taguchi design of the experiments. After the tensile test, under a scanning electron microscope, the samples were studied to see the micro-cracks and evaluated to understand the influence of the SiO<sub>2</sub> in ABS composite.

### Selection of Orthogonal Array

To select a suitable orthogonal array to conduct the experiments, the degrees of freedom are computed. The most suitable orthogonal array for experimentation is L9 array, as shown in Table 2 . Therefore, a total of nine experiments are to be carried. Taguchi's Method of parameter design can be performed with a lesser number of experimentation than full factorial analysis

and yields similar results.



**Fig 1.** Tensile tested specimens of ABS/SiO<sub>2</sub> polymer composites.



**Fig 2.** Tensometer

**Table 1.** Design factors with different levels

Factor	Symbol	Level-1	Level-2	Level-3
SiO <sub>2</sub> %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

**Table 2.** Orthogonal array (L9) and control parameters

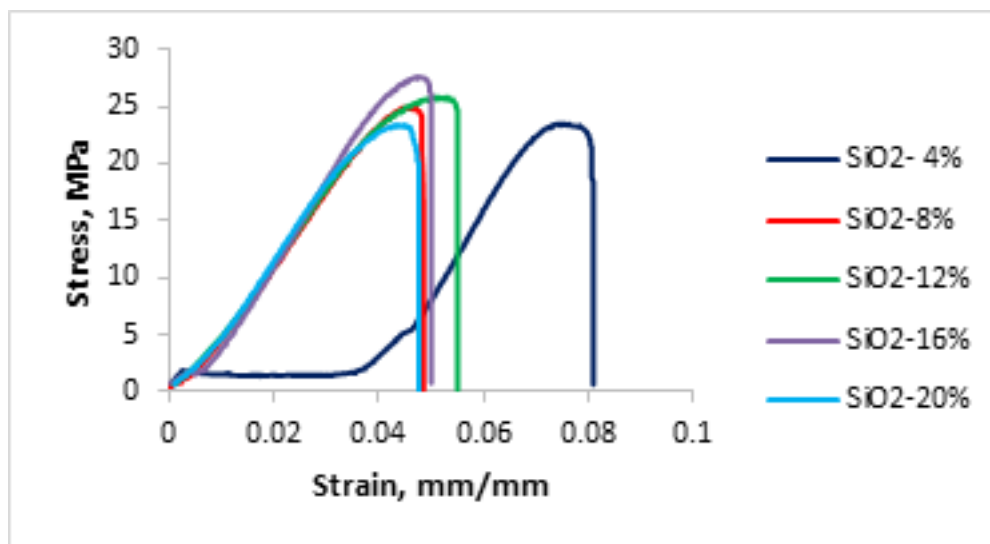
Treat No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

### 3 Results and Discussion

Wear and tensile tests for the specimens with varied compositions (4%, 8%, 12%, 16%, 20%wt) of  $\text{SiO}_2$  were conducted. The hardness was measured along with longitudinal and transverse directions of the specimens. SEM analysis was done after the tensile and wear test.

#### 3.1 Mechanical behavior of ABS/ $\text{SiO}_2$ polymer composites

The stress-strain curves of ABS/ $\text{SiO}_2$  polymer composites are shown in Figure 3. The ultimate strength increases with an increase in the content of  $\text{SiO}_2$  up to 16%wt and decreases for 20%wt. Figure 4 (a) shows that the ABS/ $\text{SiO}_2$  composite's tensile behavior shows a gradual increment from 4%wt to 12%wt. For the composition 12% to 16%, the increase continues reaching the maximum point at 16%wt of  $\text{SiO}_2$ . From 16%wt to 20%wt, tensile behavior shows a detrimental value reaching the lowest value at 20%wt. From Figure 4(b), the strain rate shows a sudden decrease from 4%wt to 8%wt of  $\text{SiO}_2$ . The strain rate increases from 8% to 12%, and then it decreases gradually from 12% to 20%wt of  $\text{SiO}_2$ .

**Fig 3.** Stress-strain curves of ABS/ $\text{SiO}_2$  polymer composites.

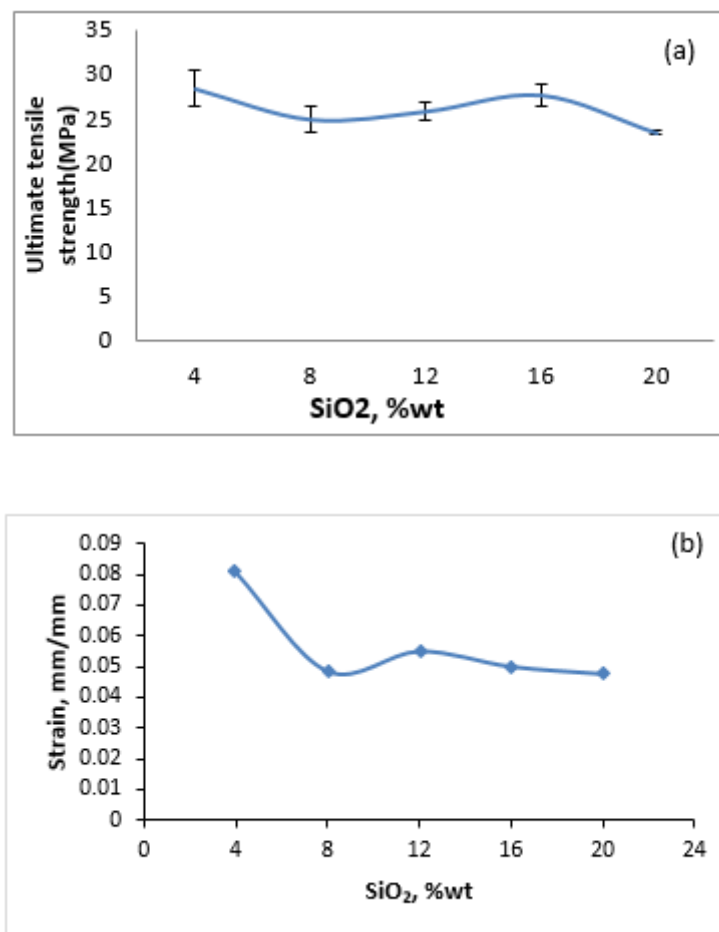


Fig 4. Ultimate strength (a) and corresponding strain (b) as a function of SiO<sub>2</sub>

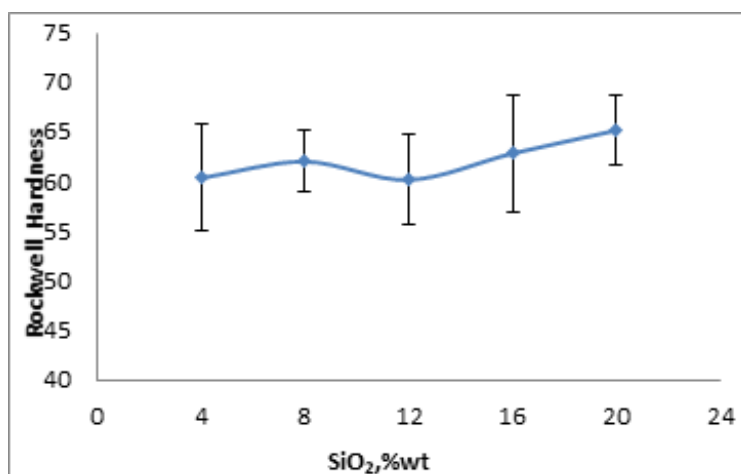


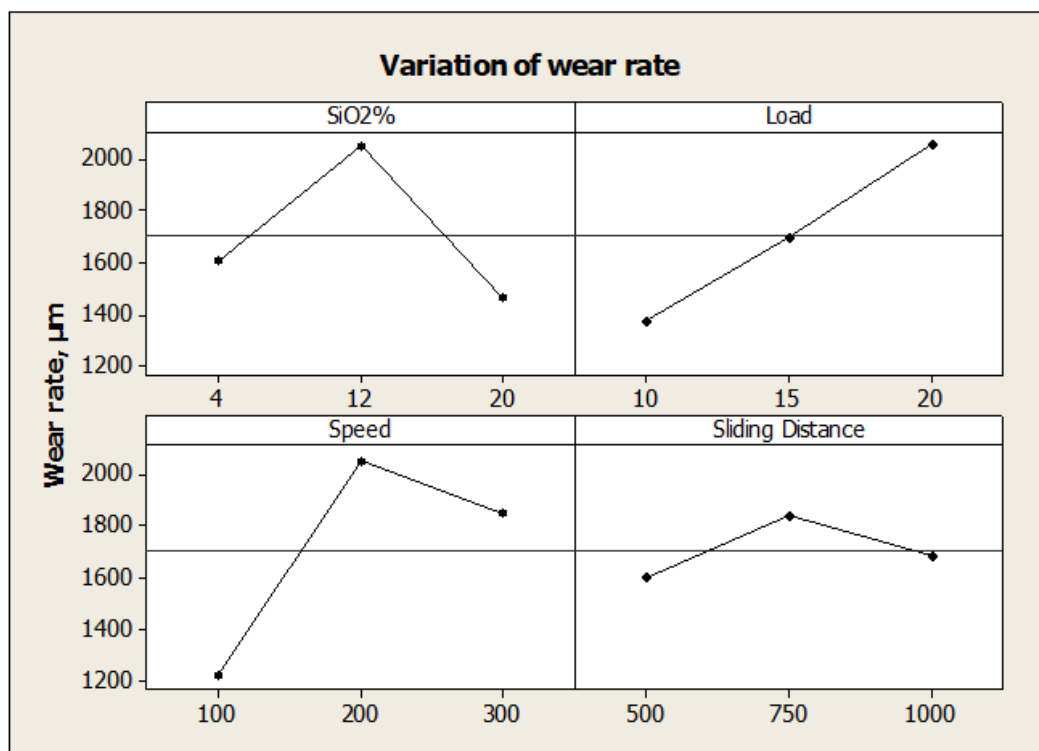
Fig 5. Hardness is a function of %wt SiO<sub>2</sub>

The hardness of ABS/SiO<sub>2</sub> polymer composites increases with the increasing content of SiO<sub>2</sub>, taken three reading each specimen surface and then average it ( Figure 5 ). The Rockwell hardness increased from 4%wt to 20wt% SiO<sub>2</sub> filler

concentration in the composite. It increases due to resistance to the plastic deformation of the ABS matrix from comparatively hard SiO<sub>2</sub> nanoparticles. The significant improvement in microhardness may be attributed to the better distribution of SiO<sub>2</sub> nanoparticles and excellent adhesion between the ABS and SiO<sub>2</sub> nanoparticles.

**Table 3.** ANOVA summary of the wear rate

Parameter	Symbol	DOF	SS	MSS	P%
wt% SiO <sub>2</sub>	A	2	567262.89	283631.445	22.81
Load	B	2	699350.88	349675.44	28.12
Speed	C	2	1131837.55	565918.775	45.51
Sliding Distance	D	2	88633.55	44316.775	3.56
Error	e	0	0.018889	..	0
Total	T	8	2487084.9		100



**Fig 6.** Variation of wear rate

As shown in Figure 6, the polymer composite with 12% wt of SiO<sub>2</sub> exhibits a higher wear rate. It increases in loads in the range of 10N to 20N, the wear rate increases as the load increases, and the wear rate is maximum at 20N. For sliding speeds in the field of 100rpm to 300rpm, wear rate increases from 100 rpm to 200 rpm reaching the maximum value at 200 rpm and later decreases from 200 rpm to 300 rpm. The sliding distance between 500 mm to 1000 mm, wear rate coming to a most extreme scope of 750 mm and afterward drop from 750 to 1000 mm.

During the SEM analysis, it was found that micro damages are less at lower proportions of SiO<sub>2</sub> (Figure 7). As the SiO<sub>2</sub> wt% increases, the micro-cracks increase gradually due to the presence of SiO<sub>2</sub> nanoparticles, and the bond strength of the material increases. For 16% wt SiO<sub>2</sub>, the SiO<sub>2</sub> material bonded energetically. This material creates layers during the wear. It can conclude that with increasing SiO<sub>2</sub>, there is an increasing trend in the bonding between the matrix material and the filler material.

Figures 8, 9 and 10 shows the SEM images of the composite during the wear test. Microcracks of the material are visible clearly, and the grooves are observed to be perpendicular to the sliding surface. These micro-cracks are uniform throughout



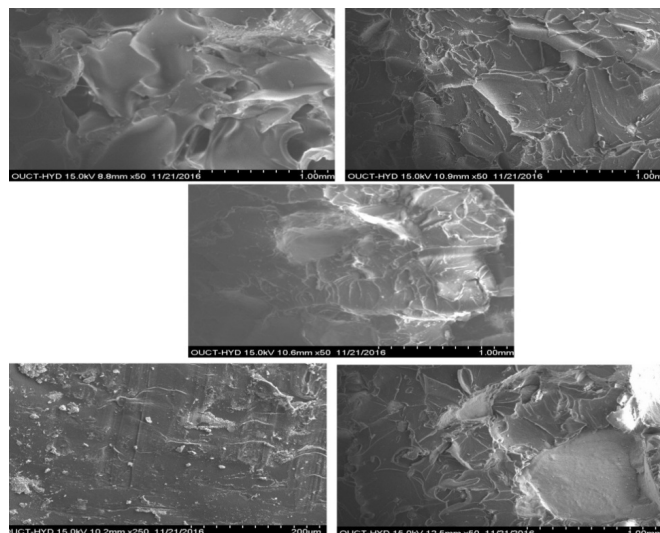


Fig 7. Fractography of ABS/SiO<sub>2</sub> polymer composites

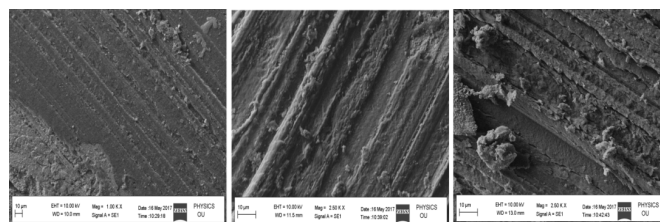


Fig 8. (a, b and c). Worn surfaces of specimens for trial conditions of 1, 2, and 3.

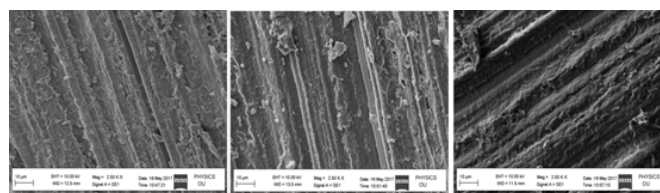


Fig 9. (a,b, and c). Worn surfaces of specimens for trial conditions of 4, 5, and 6.

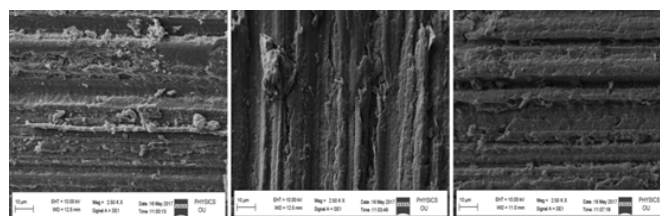
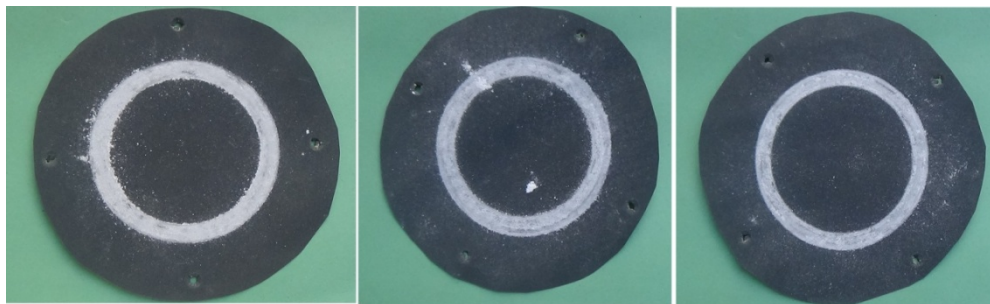


Fig 10. (a, b and c). Worn surfaces of specimens for trial conditions of 7, 8, and 9.

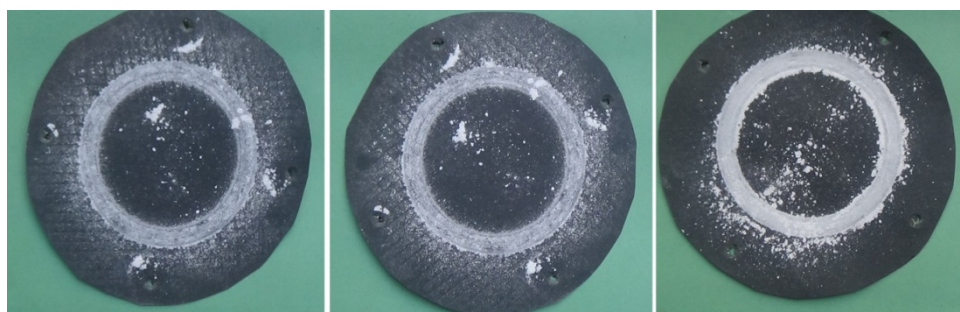
the surface. With increasing the load, there was an increase in the strength of the cracks. For trials 1, 2, and 3 with 4% SiO<sub>2</sub> nanoparticles, the worn surface appears small grooves ( Figure 8 a) for all startup conditions. As the load and sliding distance increase, large deformation and cracking of the surface were observed in the specimens, as shown in Figure 8b and Figure 8c. The situation was complicated in Figure 10b for which the normal load and sliding distance were respectively effected on that. For trials 4, 5, and 6 with 12% SiO<sub>2</sub> nanoparticles, worn surfaces were almost the same because of the high strain experienced by these specimens, as shown in Figure 9a, Figure 9b, and Figure 9c. The variation of worn surfaces was mainly due to the applied load on the samples. Width of the groove and size of dimples on the worn surface increase with increasing load. For trials 7, 8, and 9 with 20% SiO<sub>2</sub> nanoparticles, the appearance of worn surfaces for trials 7 and 9 is nearly the same( Figure 10a and Figure 10c) except trial 9. In trial 9, wherein voids and particle clustering were observed in the specimens, a large amount of plastic deformation was observed ( Figure 10b).



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



**Fig 12.** Debris of specimens for trial conditions of 4, 5, and 6.



**Fig 13.** Debris of specimens for trial conditions of 7, 8, and 9.

Wear debris of material are examined and found that with an increase of SiO<sub>2</sub> %wt, the load increases ( Figures 11, 12 and 13). The wear debris and flakes increase as the material becomes brittle due to the addition of SiO<sub>2</sub>. Similar features were also observed at the low load and high volume fraction of SiO<sub>2</sub> nanoparticles.



## 4 Conclusions.

The wear performance of acrylonitrile-butadiene-styrene (ABS) filled with nano-meter sized SiO<sub>2</sub> composites was looked into for varying filler content, normal load, sliding distance and speed with three levels of each factor as per Taguchi's design of experiments. Pin-on-disc type friction and wear monitor (ASTM G99) was working to evaluate wear behavior of ABS/ SiO<sub>2</sub> polymer composites. The deformation behavior of ABS has been governed by a considerable dilatational component indicating a modification of volume. The ultimate strength has decreased with the increasing content of SiO<sub>2</sub> in the composites.

- The percentage compositions of speed and sliding load are 45.51 % and 28.12% variation of wear rate, and the contribution of sliding distance very low at 3.56% is observed.
- The composites filled with SiO<sub>2</sub> nanoparticles showed lower wear rates at the combination of 20% wt SiO<sub>2</sub>, 100 rpm speed, 10N load, and 500 m sliding distance.
- Morphology of the fracture materials was studied and found to increase the material roughness with an increase in the material load and filler content.
- It is created that the parameter design of the Taguchi method provides a simple, systematic, and resourceful approach for optimizing the process parameters.
- Wear debris of the material shows that the flakes increase with the rise in SiO<sub>2</sub> wt%.
- Hardness maximum at 20%wt .the percentage of SiO<sub>2</sub> increases the hardness also increased because of great bonding of ABS/ SiO<sub>2</sub> Nanoparticles.

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