

MECHANICAL AND WEAR BEHAVIOR OF ABS/BN POLYMER COMPOSITES

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Abstract: In the present work, the wear behavior of acrylonitrile-butadiene-styrene (ABS) filled with nanometer sized boron nitride (BN) composites has been investigated for varying filler content, normal load, sliding distance and speed with three levels of each parameter as per Taguchi's design of experiments. A pin-on-disc type friction and wear monitor (ASTM G99) was employed to evaluate wear behavior of ABS/BN polymer composites. The major contributions of this work are the decrease of ultimate strength with increasing content of boron nitride in the composites and the normal load conversed to 54.46% of variation in the wear rate.

Keywords: ABS; BN; wear; filler content; normal load; sliding distance; speed.

1. Introduction

Acrylonitrile butadiene styrene (ABS) $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$ is a thermoplastic polymer. The most important mechanical properties of ABS are impact resistance and toughness. Because of its good shock absorbance, ABS is used for golf club heads, automotive trim components and automotive bumper bars. ABS is easily injection moulded and machined. The mechanical properties of thermoplastic polymers can be further improved with the addition of metallic fillers. Nanoscale fillers are better than micro-size fillers due to increase in surface area. In order to improve the wear resistance, fillers such as TiO_2 [1], CuO [2], CuS [3], $CaCO_3$ [4], Al [5], Fe [6], C [7], $\gamma-Fe_2O_3$ [8, 9], Al_2O_3 [10], SiC [11] and Ni [12] are used with various polymers.

Mechanical and wear behavior are the most important properties of polymer and its composites. Unfilled polymers could not satisfy the requirement wherein a combination of properties such as good mechanical and tribological properties is required. Current understanding is that internal cavitation of the elastomeric phase can relieve stress triaxiality ahead of flaws, thereby enhancing localized shear deformation. Wear is complex phenomenon and its mechanism depends on many parameters such as chemical and physical properties of polymer, load, filler quantity, sliding distance and sliding speed [13, 14]. In the present work, boron nitride (BN) nanoparticles are filled in the ABS matrix. Boron nitride has a crystal structure similar to graphite layered structure. It not only has a low coefficient of thermal expansion, but also high thermal conductivity. It is a good conductor of heat and electrical insulator. Boron nitride combines such features as electrical insulation, thermal conduction, and high-temperature lubricity.

The wear behavior of acrylonitrile-butadiene-styrene (ABS) filled with nano-meter sized boron nitride (BN) composites are investigated for varying filler content, normal load, sliding distance and speed with three levels of each parameter as per Taguchi's design of experiments. The morphology of wear tracks is also studied for the initial and optimum conditions of the parameters after the tribological tests using SEM microstructures.

2. Materials and Methodology

The matrix material was the ABS thermoplastic powder. The filler material was BN with particle size approximately 100nm. The Boron nitride was added to ABS in various percentages such as 4%, 8%, 12%, 16% and 20% by weight in order to improve the wear resistance of the polymer composite. The BN nanoparticles were mixed with the ABS in a ME100LA mixer at a temperature of 190 °C. The mixing time was 20 min, and the speed of the mixing blades was 200 rpm. Injection moulding machine was employed to fabricate ABS/BN polymer composites. The mixture of ABS and BN nanoparticles was placed in the hopper. The ABS was heated in the barrel so that it became molten and soft. The mixture of liquid ABS and BN nanoparticles was then forced under pressure inside a mould cavity where it was subjected to holding pressure for a specific time to compensate for material shrinkage. The melting point of the ABS used was 230 °C and its melt flow index was 12 g per 10 min. For all samples, the heating temperature of the charge barrel, injection pressure and the cooling time of moldings were kept constant. The temperature of the mould was 25 °C for all experiments. The injection

pressure 70 MPa. The material would solidify as the mould temperature was decreased below the glass transition temperature (105 °C) of the ABS. After sufficient time, the material was frozen into the mould shape and got ejected. Standard tensile specimens were fabricated under different injection pressures and packing pressures. The dimensions of tensile specimens are shown in Fig.1. Tensometer Model PC-2000 (Fig. 2) was used to carry tensile tests. Microstructures were observed with a scanning electron microscope (S-3000N Toshiba SEM) to study the fracture surfaces of the tensile specimens at room temperature.

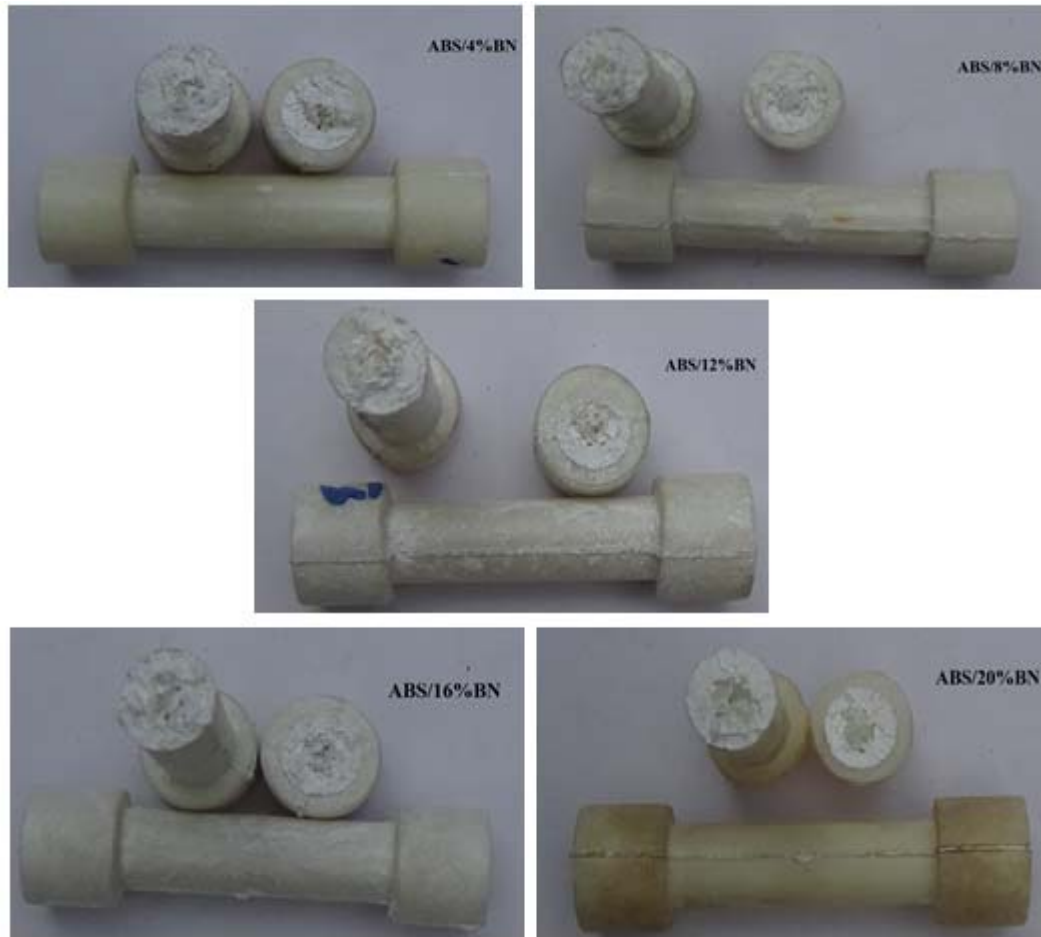


Fig. 1. Tensile tested specimens of ABS/BN polymer composites.

A pin-on-disc type friction and wear monitor (ASTM G99) was employed to evaluate wear behavior of ABS/BN polymer composites against emery paper (grade size of 400) fixed on a hardened ground steel (En32) disc. The wear tests were designed as per Taguchi's design of experiments. The levels chosen for the controllable process parameters are summarized in Table 1. The orthogonal array, L9 was preferred to carry out wear experiments (Table 2). Vickers micro hardness was conducted for ABS/BN polymer composites. Scanning electron microscopy analyses were also carried out to find consequence of wear test of ABS/BN polymer composite specimens.



Fig. 2. Tensometer

Table 1. Control parameters and 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

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

Three tensile and wear specimens of each of the different compositions were tested. The displacement rate used for all tensile testing was 1.0 mm min⁻¹. The hardness was measured along the transverse and longitudinal directions of the specimens.

3.1 Mechanical behavior of ABS/BN polymer composites

The tensile stress—strain curve is shown for the unreinforced ABS in Fig. 3. This curve shows that the ABS reached its ultimate strength at the yield point A. The break point is B. It shows a proportional limit followed by a maximum (at A) in the curve at which necking takes place. The deformation behavior of ABS is known to be governed by a substantial dilatational component which indicates a change of volume. The damage occurs initially at two separate sites. The first site could be microvoids and microcracks radiating from the center of the specimen (Fig. 3c). The second site could be microcracks parallel to the specimen axis, starting at the equatorial midline of the cylindrical wall (Fig. 3d). Microcracking and microvoid formation, their growth and coalescence lead to final failure.

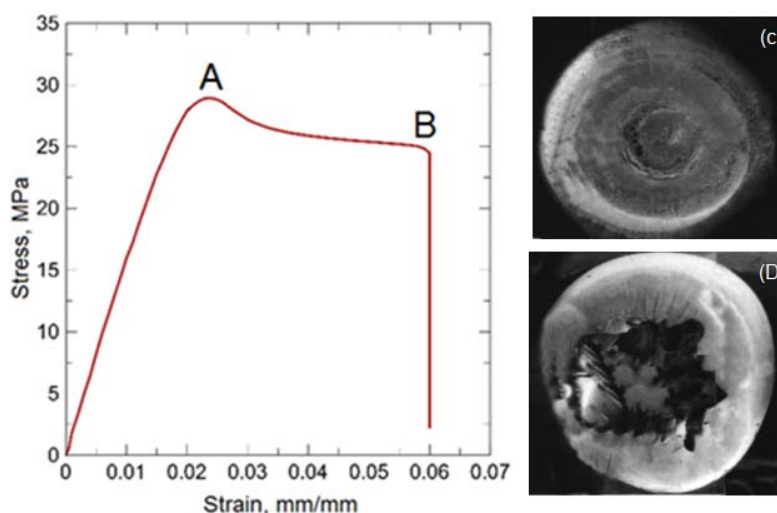


Fig. 3. Stress-strain curve of ABS.

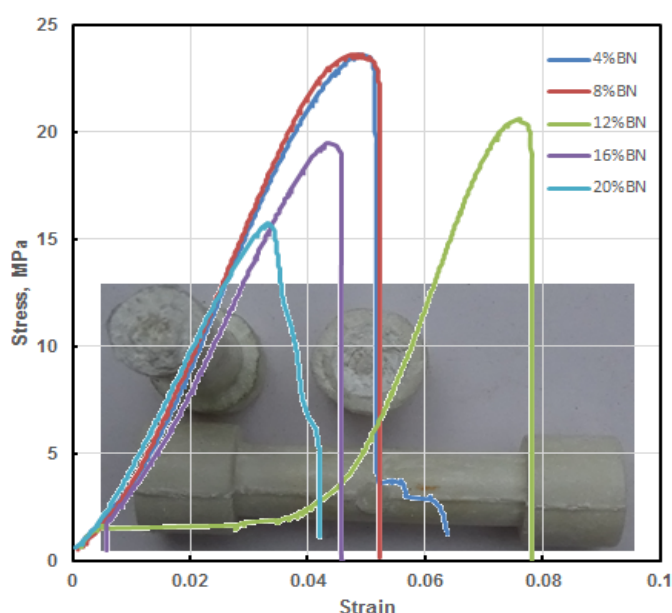


Fig. 4. Stress-strain curves of ABS/BN polymer composites.

The tensile stress—strain curves of ABS/BN polymer composites are shown in Fig. 4. The ultimate strength decreases with increasing content of boron nitride in the composites as shown in Fig. 5a. A change from 4%wt to 8%wt of BN does not influence the tensile behavior of ABS/BN polymer composites. The tensile behavior of ABS/12%wt of BN polymer composite is different to other compositions of ABS/BN polymer composites. This is observed from Fig. 5b that the strain at ultimate tensile strength of ABS/12%wt of BN polymer composite is higher than strain of other compositions of ABS/BN polymer composites.

The hardness of ABS/BN polymer composites increases with increasing content of BN as shown in Fig. 6. The micro hardness increased from 5.60Hv for as such ABS sample to 14.55Hv for 20wt%BN filler concentration in the composite. It increases due to resistance to the plastic deformation of the ABS matrix from comparatively hard BN nanoparticles. The significant improvement in microhardness may be attributed to the better distribution of BN nanoparticles and good adhesion between the ABS and BN nanoparticles.

The fractographies of Pure ABS and ABS/BN polymer composites are shown in Fig. 7. Voids and fibrillation were observed in the fracture surface of pure ABS as shown in Fig. 7a. The fibrillation caused by the debonding in the ABS. Stress whitening is also appeared on the cross-section of the fractured specimens of ABS. In ABS/BN polymer composites as shown in Fig. 7, the damages are initiated locally in the matrix ABS. There are the micro-damages propagated along the nanoparticle/matrix interface initially. These micro-damages grow until the interface degradation is achieved and the nanoparticle-matrix bonding is lost. For all the cases shown in Fig. 7b to 7f, the characteristic marks of reinforcing BN nanoparticles have been observed on damage surface. The ABS/BN composite specimens, which have less content of BN nanoparticles, have broken at higher stresses. The fracture surfaces of ABS/4%BN, ABS/12%BN and ABS/8%BN composites have rougher surfaces

and more crack branching. Many of the crack origin sites have evidence of debonding around the flaw periphery. The debonding causes light to reflect at the flaw periphery, causing the flaws to stand out quite clearly as dark areas or bright spots if they reflected light back to the viewer. The flaws are the filler agglomerates or the regions of nonuniform mixing in the ABS/BN polymer composites. The fracture surfaces of ABS/16%BN and ABS/20%BN composites have multiple cracks and deep channels in the matrix ABS, parallel to each other, oriented in the direction perpendicular to the BN nanoparticles. Radially propagating crack growth direction lines are the symptoms of brittle cracking in the ABS/BN polymer composites.

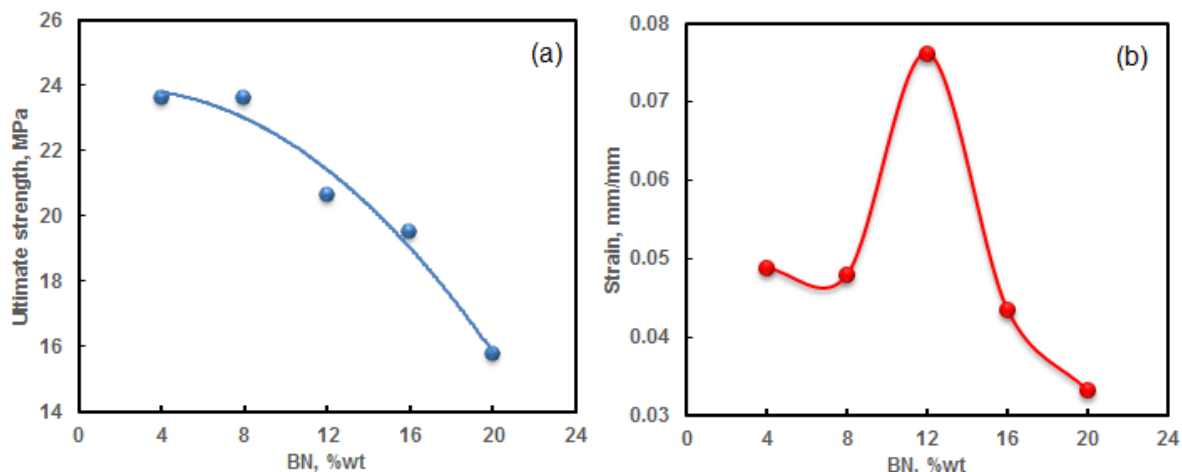


Fig. 5. Ultimate strength (a) and corresponding strain (b) as a function of BN.

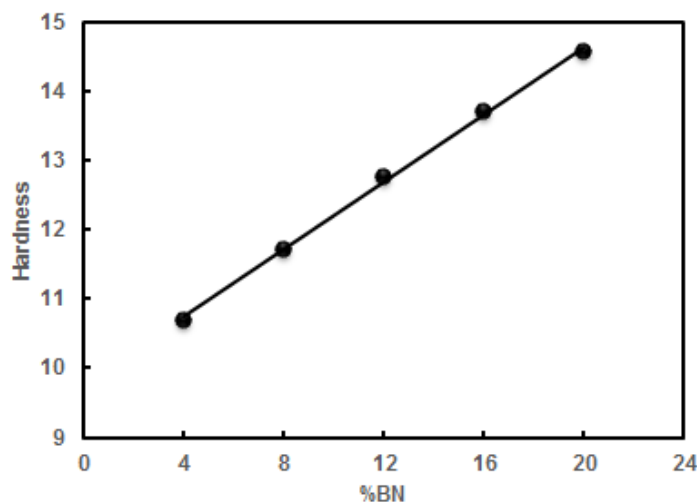


Fig. 6. Hardness as a function of BN.

3.2 Wear behavior of ABS/BN polymer composites

The percent contribution indicates that the weight fraction of BN, extends 16.89% to the variation in the wear rate as given in Table 3. The normal load confers 54.46% of variation in the wear rate. The sliding speed accords 10.99% of variation in the wear rate. The sliding distance provides 17.67% of the total variation in the wear rate.

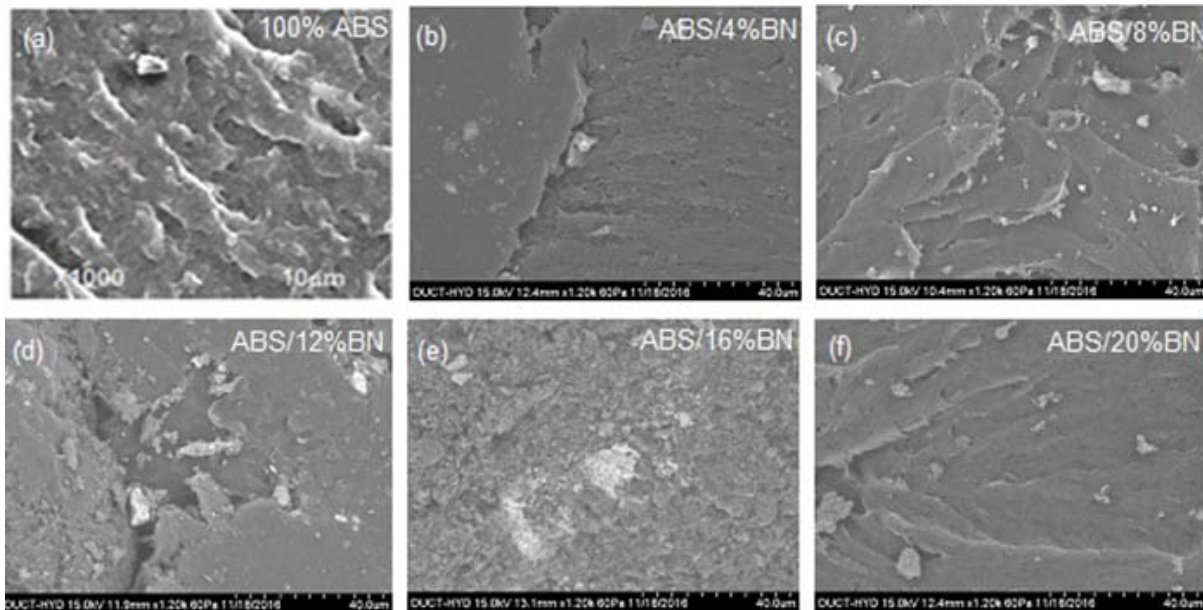


Fig. 7. Fractography of Pure ABS and ABS/BN polymer composites.

Table 3. ANOVA summary of the wear rate

Parameter	Symbol	sum1	sum2	sum3	SS	v	V	P
BN	A	4866	6151	5205	2.96E+05	2	1.48E+05	16.89
Normal Load	B	4030	6010	6182	9.53E+05	2	4.77E+05	54.46
Sliding Speed	C	4992	6014	5216	1.92E+05	2	9.62E+04	10.99
Sliding Distance	D	4968	5062	6192	3.09E+05	2	1.55E+05	17.67
Error	e	9022	12024	11398	3.73E-09	1	3.73E-09	0.00
	T				1.75E+06	9		100.00

Examining the wear rate obtained as a result of wear tests, it is seen from Fig. 8a that the weight loss is very high for weight fraction of 12%BN. Wear tests were conducted with loads ranging from 10 to 20 N. All tests were conducted at room temperature. The wear rate of the composites increases as the applied load increases (Fig. 8b). For the sliding speed of 200 rpm, the wear rate (Fig. 9a) is very high. The variation of wear rate with sliding distance of ABS/BN composites is shown in Fig. 9b. It is observed that the wear rate of the composites increases with the increase in the sliding distance.

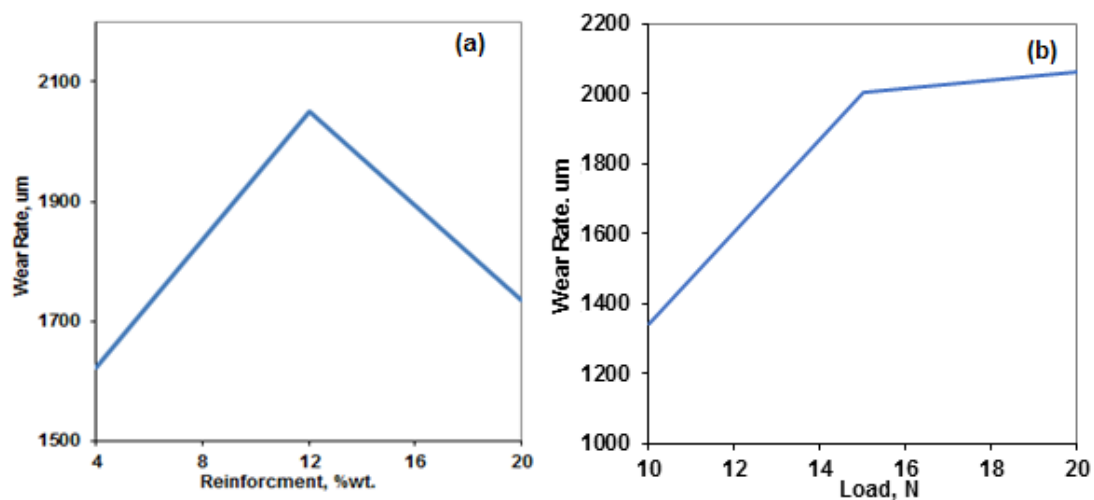


Fig. 8. Variation of wear rate with (a) weight fraction of BN and (b) normal load.

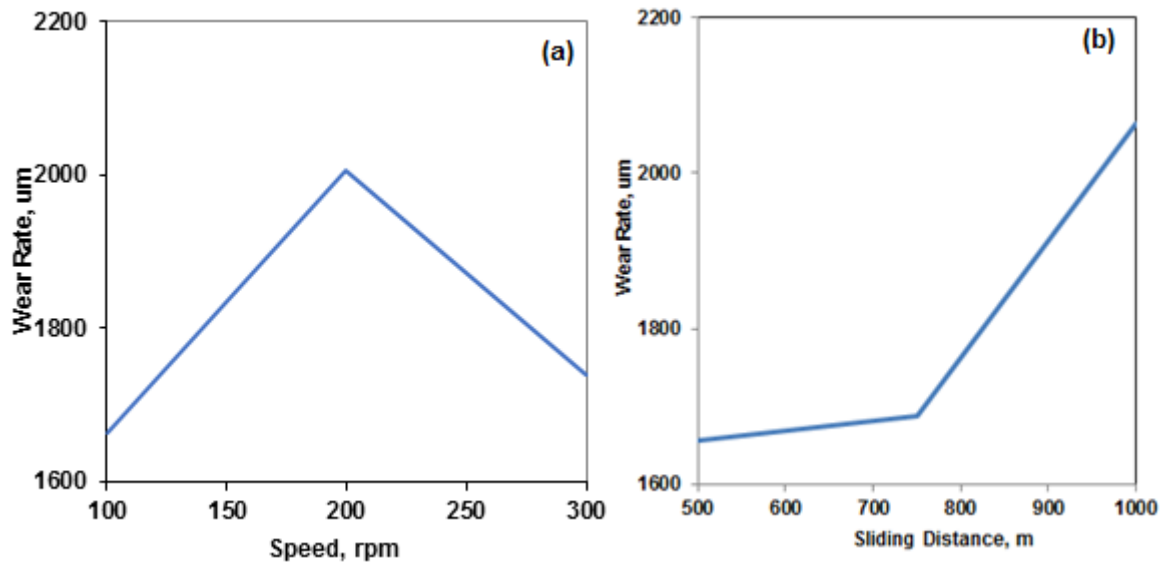


Fig. 9. Variation of wear rate with (a) sliding speed and (b) sliding distance.

For trials 1, 2 and 3 with 4% BN nanoparticles, the worn surface appears of small grooves (Fig. 10a) 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 Fig. 10b and 10c. The situation was severe in Fig. 12c for which the normal load and sliding distance were respectively, 20 N and 1000 m. For trials 4, 5 and 6 with 12% BN nanoparticles, the worn surfaces were almost same because of high strain experienced by these specimens as shown in Fig. 11a, 11b and 11c. The variation of worn surfaces was mainly due to the applied load on the specimens. Width of the groove and size of dimples on the worn surface increase with increasing load. For trials 7, 8 and 9 with 20% BN nanoparticles, the appearance of worn surfaces for trials 7 and 8 is nearly same (Fig. 12a and 12b) except trial 9. In case of trial 9 wherein voids and particle clustering were observed in the specimens, a large amount of plastic deformation was observed (Fig. 12c).

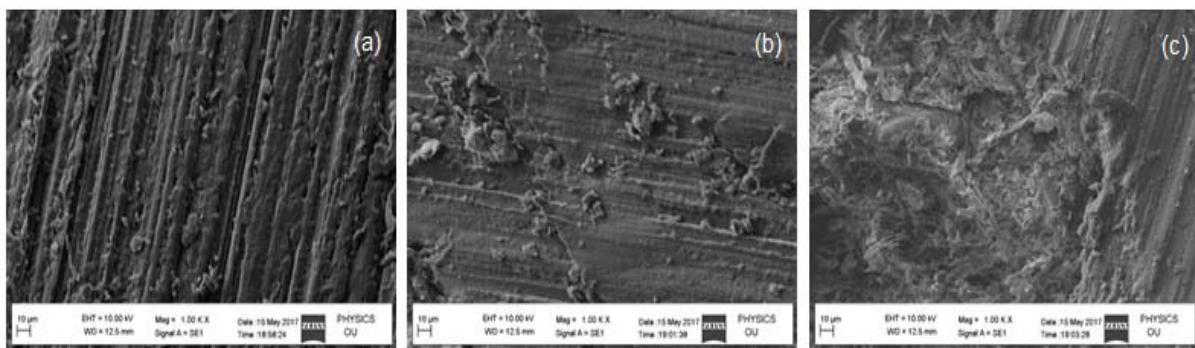


Fig.10. Worn surfaces of specimens for trial conditions of 1, 2 and 3.

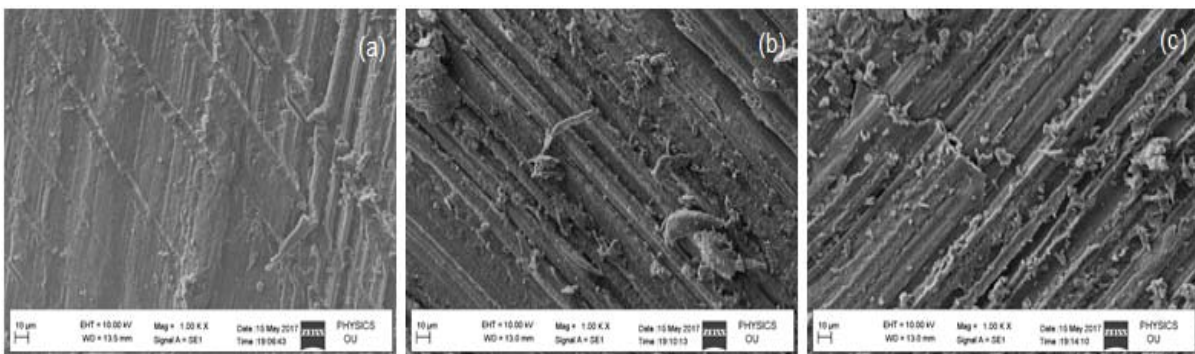


Fig. 11. Worn surfaces of specimens for trial conditions of 4, 5 and 6.

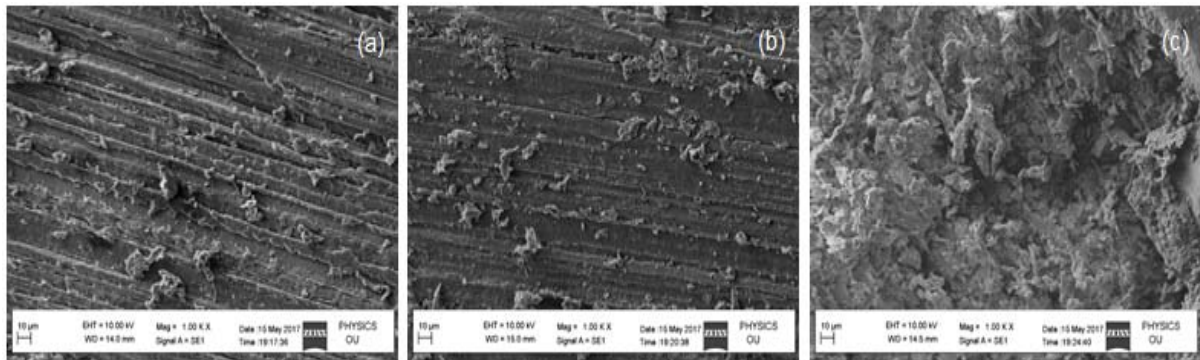


Fig. 12. Worn surfaces of specimens for trial conditions of 7, 8 and 9.

In the present work, the wear debris generated during the wear tests was collected Fig. 13, 14 and 15. With increasing applied load and sliding distance, the size of the platelets or flakes became larger and their amount increases. The similar features was also observed at the low load and high volume fraction of BN nanoparticles, where the debris was composed of only fine powders.

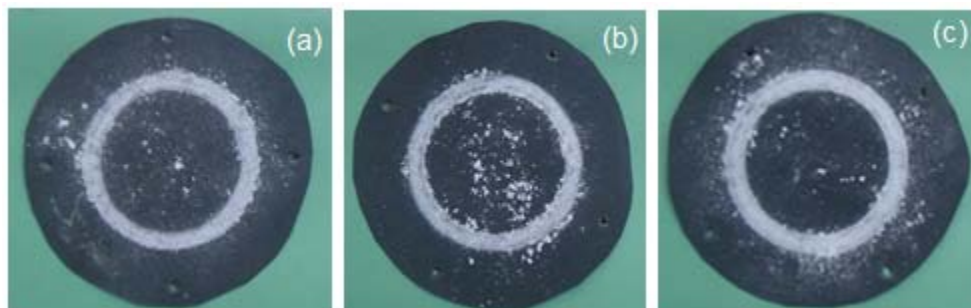


Fig. 13. Debris of specimens for trial conditions of 1, 2 and 3.

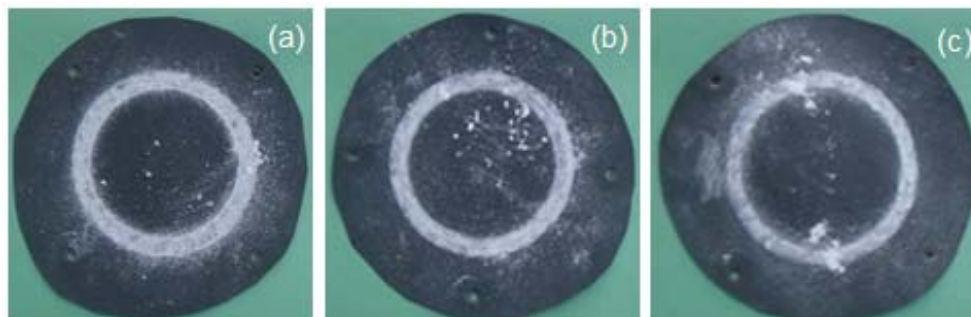


Fig.14. Debris of specimens for trial conditions of 4, 5 and 6.

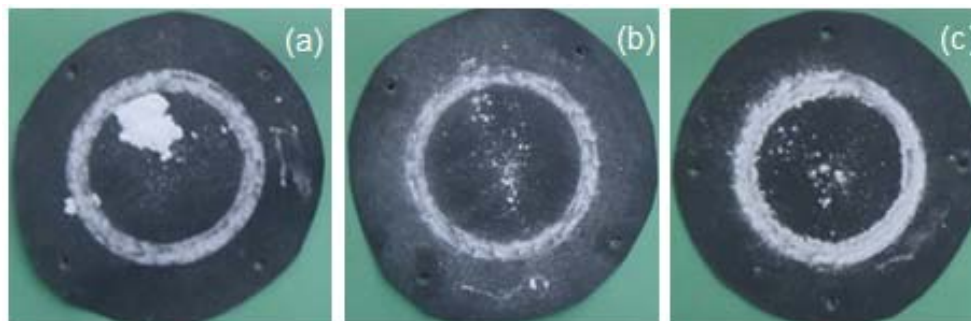


Fig. 15. Debris of specimens for trial conditions of 7, 8 and 9.

4. Conclusions

The wear behavior of acrylonitrile-butadiene-styrene (ABS) filled with nano-meter sized boron nitride (BN) composites were investigated for varying filler content, normal load, sliding distance and speed with three levels of each parameter as per Taguchi's design of experiments. A pin-on-disc type friction and wear monitor (ASTM G99) was employed to evaluate wear behavior of ABS/BN polymer composites. The deformation behavior of ABS has governed by a substantial dilatational component indicating a change of volume. The ultimate strength has decreased with increasing content of boron nitride in the composites. The flaws were the filler agglomerates or the regions of nonuniform mixing in the ABS/BN polymer composites. Radially propagating crack growth direction lines were the symptoms of brittle cracking in the ABS/BN polymer composites. The normal load has conferred to influence 54.46% of variation in the wear rate. The wear rate of the composites was also increased as the applied load increased. As the load and sliding distance were increased large deformation and cracking of the surface were observed in the specimens.

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