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Investigation on mechanical properties and wear performance of Nylon-6/Boron Nitride polymer composites by using Taguchi Technique

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A R T I C L E I N F O

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A B S T R A C T

We study a tensile property test was conducted to investigate the mechanical behavior of nylon-6 and its composites. The wear conduct of Nylon-6 loaded up with nanometer measured boron nitride (BN) composites has been explored for changing filler content, normal load, sliding distance and speed with three levels of every parameter according to Taguchi's design of experiment. A pin-on-disk compose erosion and wear test (ASTM G99) was utilized to assess wear conduct of Nylon-6/BN polymer composites. The significant commitments of this work are the decline of extreme quality with expanding substance of boron nitride in the composites and the normal load converted to 71.54% of variety in the wear rate. To improve the mechanical properties of Nylon-6/BN composites will enhance the application of pure comparative the pure Nylon-6.

1. Introduction

Nylon, a semi-crystalline engineering thermoplastic due to its exceptional strength, modulus, stiffness, wear resistance and chemical resistance attracts a large number of engineering applications. Nylon-6 is used in extensive range for its inviting combination of good processability and mechanical properties. Nylon-6 is mostly used in bearings, fittings, cams and gears. The wear behaviour of Nylon-6 is suitable for dry sliding situations. Lubrication at high speeds is achieved by adding nano-solid lubricants to the polymer matrix, which strengthens Nylon mechanical properties. Nylon-6 is easily injection moulded and machined. Metallic fillers are added to thermoplastic polymers to enhance their mechanical properties. Some researchers viz., Satheeskumar [1] studied the mechanical behavior of PA6 and Al_2O_3 reinforced PA6 polymer composites. The wear behavior and friction of PA6 sliding allied with steel at low velocity under exceptionally high contact pressures was investigated by Van De[2]. Senthilvelan and Gnanamoorthy [3] observed fiber reinforcement in injection moulded Nylon 6/6 spur gears. Mohammad et al. [4] studied results of nanoparticles of SiO_2 on thermal and tensile performance of Nylon-6. Karan Agarwal [5] studied enrichment in mechanical performance of Nylon/Teflon composites on adding nano Iron Oxide (γ-Fe_2O_3). Thermal properties and mechanical properties of nano Al_2O_3/Nylon-6 composites were investigated by Li yunzheng et al. [6]. A.C.Reddy [7] studied classification of tribological and mechanical performance of Nylon-6 + graphite + Teflon nano particulate composite function perspective. Li [8] studied the effect of PA6 content on the mechanical and tribological properties of PA6 reinforced PTFE composites. Effect of particle size of filler on properties of Nylon-6 was investigated by Suryasarathi and Mahanwar [9]. Seunggun Yu, Do-Kyun Kim et al. [10] have addressed the thermal conductivity show of SiC–Nylon 6,6 and hBN–Nylon 6,6 composites. Fadiran et al.[11] studied pollen fillers for reinforcing and epoxy composites arestrengthening the composite. Tribological behaviors of pure and glass fiber reinforced Nylon-6 composites against polymer disc was studied by Sudhir Kumarand K. Panneerselvam[12]. Li Chang and KlausFriedrich [13] investigated on Enhancement effect of nanoparticles on the sliding wear of short fiber-reinforced polymer composites: A critical discussion of wear mechanisms.

The wear behaviour of Nylon-6 filled with nano-meter sized boron nitride (BN) composites has been investigated for varying filler content, normal load, sliding speed and sliding distance with three levels of each parameter as per Taguchi's design of experiments. The structure of wear paths was also studied for the initial and optimal conditions of the parameters after the tribological tests using SEM microstructures.

2. Materials and Methodology

The matrix material is the Nylon-6 thermoplastic powder. The other constituent material is BN with particle size approximately 80 nm. Boron nitride was added to Nylon-6 in various percentages such as 4%, 8%, 12%, 16% and 20% by weight to improve the wear resistance of the polymer composite. The BN nanoparticles were mixed with the Nylon-6

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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 Nylon-6/BN polymer composites. The mixture of Nylon-6 and BN nanoparticles was placed in a hopper. The Nylon-6 was heated in the barrel so that it became molten and soft. The mixture of liquid Nylon-6 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 Nylon-6 used was 220 °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 mouldings were kept constant. The temperature of the mould was 25 °C for all experiments. The injection pressure was 70 MPa. The material would solidify as the temperature of the mould was decreased below the temperature of glass transition (105 °C) of the Nylon-6. After adequate time, the material was frozen into the shape of the mould and is ejected. Standard tensile specimens were fabricated under different injection pressures and packing pressures. The dimensions of tensile specimens are shown in Fig. 1 was used to carry tensile tests. SEM - Scanning Electron Microscope is used to observe microstructures at room temperature to investigate the fracture surfaces of tensile specimens.

A pin-on-disc type wear and friction monitor (ASTM G99) was used to evaluate wear behavior of NYLON-6/BN polymer composites against emery paper (grade size of 400) fixed on a hardened ground steel (En32) disc. The wear tests were designed according to Taguchi's design of experiments. The levels preferred for the controllable process parameters are outlined in Table 1. Wear experiments are carried with the L9 orthogonal array as given in Table 2. Rockwell hardness test was conducted for Nylon-6/BN polymer composites. SEM analysis was also carried out to find consequence of wear test of Nylon-6/BN polymer composite specimens (see Tables 3 and 4).

3. Results and Discussions

The tensile and wear specimens of varied compositions were tested. The displacement rate used for all tensile testing was 1.0 mm min~1. The

Table 1
Levels of Control parameters.

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.

Trial 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

Table 3
ANOVA before pooling.

Parameter	ANOVA before pooling				
	Symbol	DOF	SS	MSS	P%
BN, %wt.	A	2	161681	80840	7.96
Normal Load, N	B	2	1453151	726575	71.54
Sliding Speed, rpm	C	2	228870	114435	11.27
Sliding distance, m	D	2	187627	93813	9.24
Error	e	0	..	..	0
Total	T	8	2031328		100

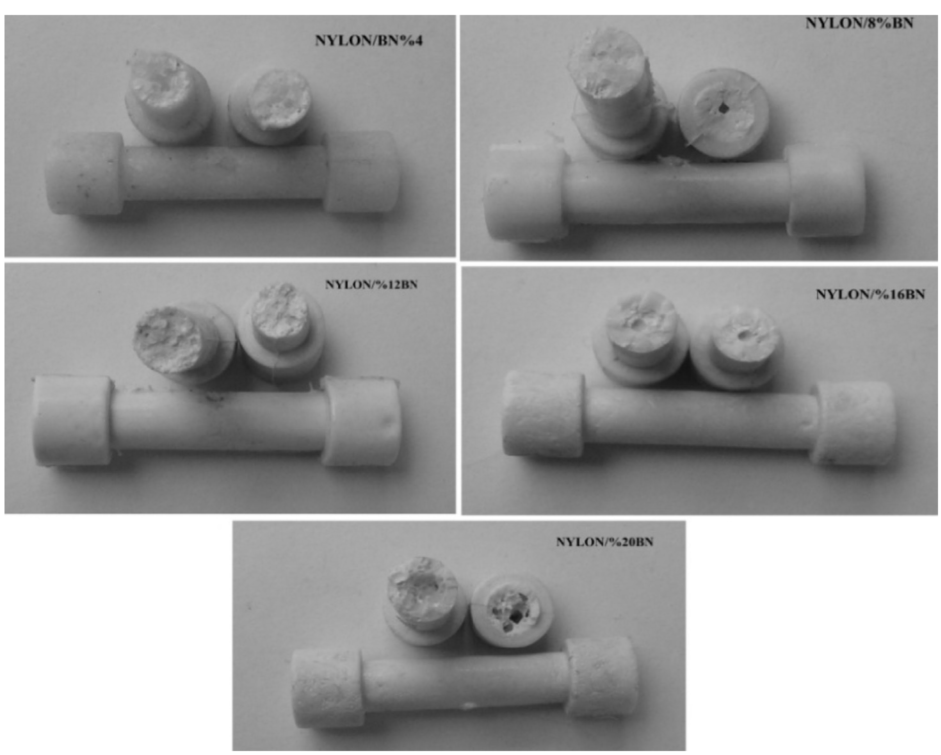

Fig. 1. Tensile tested specimens of NYLON-6/BN polymer composites.

Table 4
ANOVA after pooling.

Parameter	ANOVA after pooling				
	Symbol	DOF	SS	MSS	P%
BN, %wt.	A	2	161681	**pooled**	..
Normal Load, N	B	2	1453151	726575	66.26
Sliding Speed, rpm	C	2	228870	114435	10.43
Sliding distance, m	D	2	187627	93813	8.55
Error	e	0	0	..	..
Pooled error		2	161681	80840	7.37
Total	T	8	2193010		

SS: sum of the squares, MSS: Mean sum of the squares.
P%: Percentage contribution, DOF: degrees of freedom.

hardness was measured along the transverse and longitudinal directions of the specimens.

3.1. Mechanical behavior of NYLON-6/BN polymer composites

The tensile stress-strain curves of Nylon-6/BN polymer composites are shown in Fig. 2. The ultimate strength decreases with increasing content of boron nitride in the composites as shown in Fig. 3 (a) A change from 4%wt to 8%wt of BN has much influence on the tensile behavior of Nylon-6/BN polymer composites. For the composition of 8% and 12% there is not much difference in the tensile behavior. For the composition of 12% and 16% there is much difference in the tensile behavior. For the compositions of 16% and 20% the tensile strength is very much low compared to other compositions. It is observed from Fig. 3 (a) that the ultimate tensile strength of Nylon-6/BN polymer composite is reduced gradually and from Fig. 3 (b) that the strain rate decreases from 4% to 8% and then it increased gradually for further compositions up to 20%.

A change from 4%wt to 8%wt of BN shows a small decrease in the Rockwell hardness of Nylon-6/BN polymer composites as shown in Fig. 4. The hardness of Nylon-6/BN polymer composites is highest (93 HRM) at 12%composition of BN. It increases due to resistance to the plastic deformation of the Nylon-6 matrix from comparatively hard BN nanoparticles. The significant improvement in hardness may be attributed to the better distribution of BN nanoparticles and good adhesion between the Nylon-6 and BN nanoparticles.12%wt to 16%wt of BN shows a small decrease in the hardness of Nylon-6/BN polymer composites. There is no much difference in the hardness for 16%wt to 20%wt of BN.

The fractographies of Pure Nylon-6 and Nylon-6/BN polymer composites are shown in Fig. 5. Voids and fibrillation were observed in the fracture surface of pure Nylon-6 as shown in Fig. 5 (a). The fibrillation is caused by the debonding in the Nylon-6. Stress whitening also appears on the cross-section of fractured Nylon-6 specimens. In Nylon-6/BN polymer

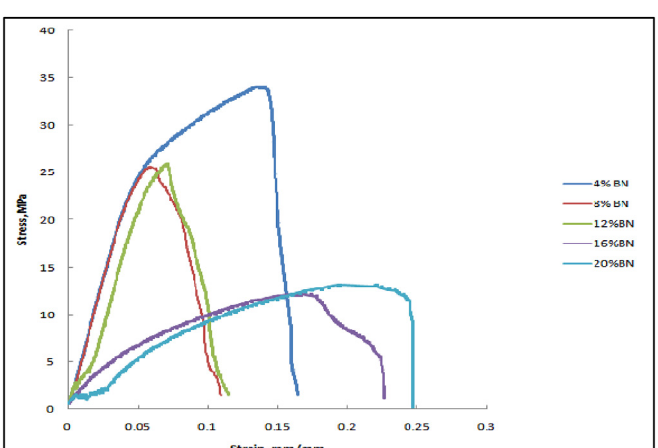

Fig. 2. Stress-strain curves of NYLON-6/BN polymer composites.

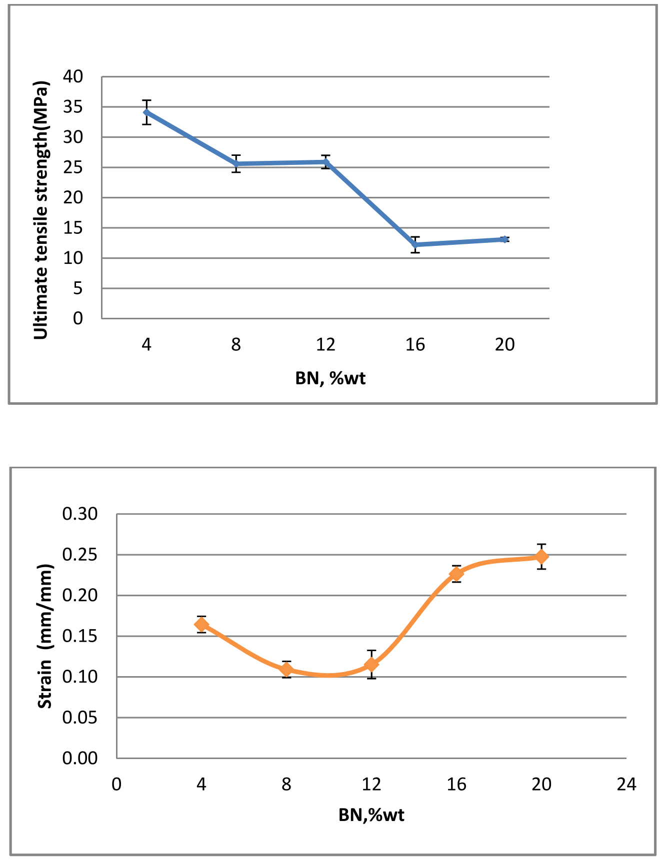

Fig. 3. Ultimate strength (a) and corresponding strain (b) Strain as a function of BN.

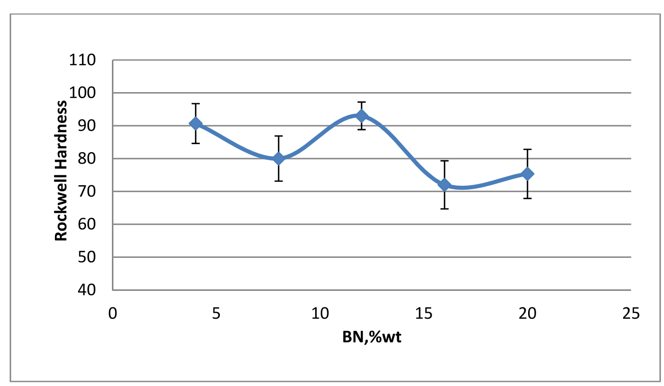

Fig. 4. Hardness is a function of %BN.

composites as shown in Fig. 5 (b)- 5(f), the damages are initiated locally in the Nylon-6 matrix. There are micro-damages propagated along the nanoparticle/matrix interface initially. These micro-damages spread until the interface degradation is reached and the nanoparticle-matrix bonding is lost. For all the cases shown in Fig. 5 (b) to 5(d), the characteristic marks of reinforcing BN nanoparticles have been observed on damage surface. The Nylon-6/BN composite specimens, which have less content of BN nanoparticles, have broken at higher stresses. The fracture surfaces of Nylon-6/4%BN, Nylon-6/8%BN and Nylon-6/20%BN composites have rougher surfaces and more crack branching. Debonding around the flaw periphery has been observed inmany crack origin sites. The debonding reflects light at the flaw periphery causing the flaws to project as dark areas or bright spots in case light is reflected back tothe observer. These flaws are the agglomerates of filler material or the regions of non-uniform mixing in the Nylon-6/BN polymer composites. The

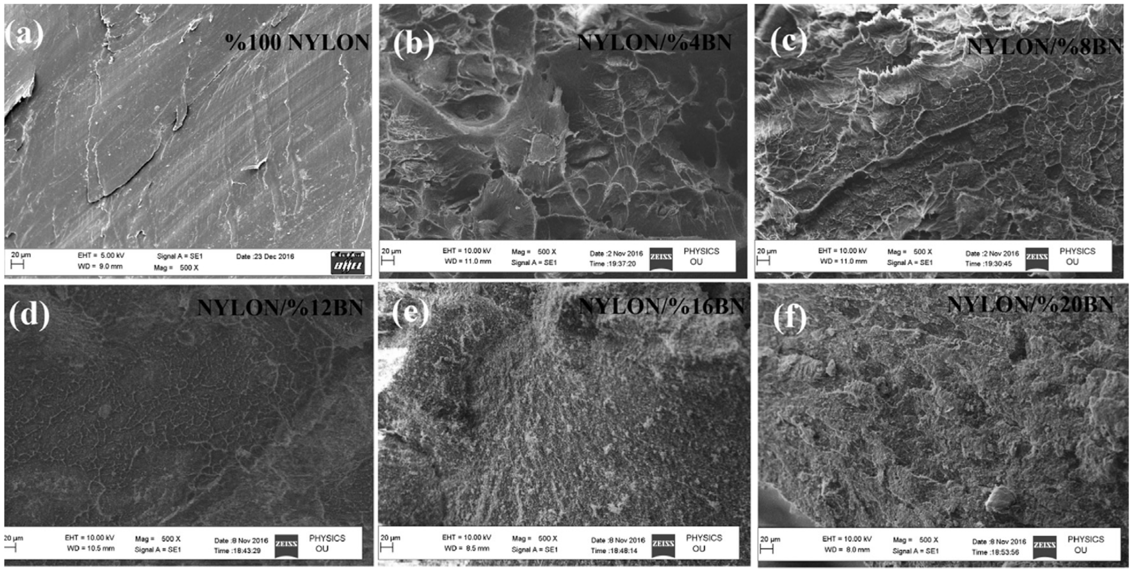

Fig. 5. Fractography of Pure Nylon-6 and Nylon-6 - BN polymer composites.

fracture surfaces of Nylon-6/12%BN, Nylon-6/16%BN and Nylon-6/20% BN composites have multiple cracks and deep channels in the matrix of Nylon-6, parallel to each other, aligned at 90° to BN nanoparticles. Brittle cracking symptoms in the Nylon 6/BN polymer composites are crack growth direction lines that are propagated radially.

From Fig. 6 the weight fraction of 4%BN shows higher wear rate. Also, the wear rate increases with increase in application of load by experimenting with loads ranging from 10 to 20 N. For sliding speed in range 100 rpm to 300 rpm, wear rate decreases from 100 rpm to 200 rpm and increases from 200 rpm and reached highest value at 300 rpm. Wear rate increases within the increasing range of sliding distance. Worn surfaces of specimens for trial conditions of 1,2 and 3 are shown in Fig. 7. For trials 1, 2 and 3 with 4% BN nanoparticles, the worn surface shows up little scores as revealed from Fig. 7 (a) and 7 (b) for all startup situations. As the load and sliding separation increments, vast deformation and splitting of the surface were seen in the examples as appeared in Figs. 7 (c) and 8 (d). The circumstances were severe in Fig. 3(a) and (b) for which the ordinary load and sliding separation were individually, 20 N and 1000 m respectively. For trials 4, 5 and 6 with 12% BN nanoparticles, the worn surfaces were relatively same as a result of high strain experienced by these specimens as appeared in Figs. 7 (c), 8 (d) and 9 (h). The width of the groove and size of dimples on the worn surface increments with expanding loads. For trials 7, 8 and 9 with 20% BN nanoparticles, the presence of worn surfaces for trials 7 and 8 is about same (Fig. 9 (g) and 9 (h)) with the exception of trial 9. In trial 9, voids, molecule grouping and a lot of plastic disfigurement was watched (Fig. 9 (h)).

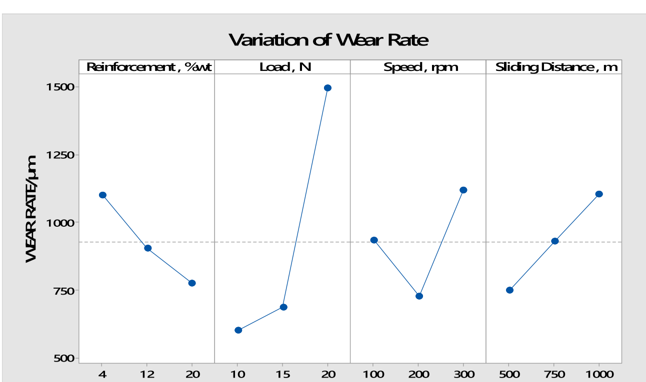

Fig. 6. Variation of wear rate.

4. Conclusions

The mechanical property, tensile strength increases at 4% of BN and decreases at 16% of BN for BN/Nylon-6 composites. On increasing the filler contents of %BN, the Rockwell hardness is observed to be maximum at 12%BN. The wear behavior of Nylon-6 loaded up with nano-meter measured boron nitride (BN) composites were researched for fluctuating filler content, normal load, sliding distance and speed with three levels of every parameter according to Taguchi's plan of trials. A pin-on-disc compose friction and wear monitor (ASTM G99) was utilized to

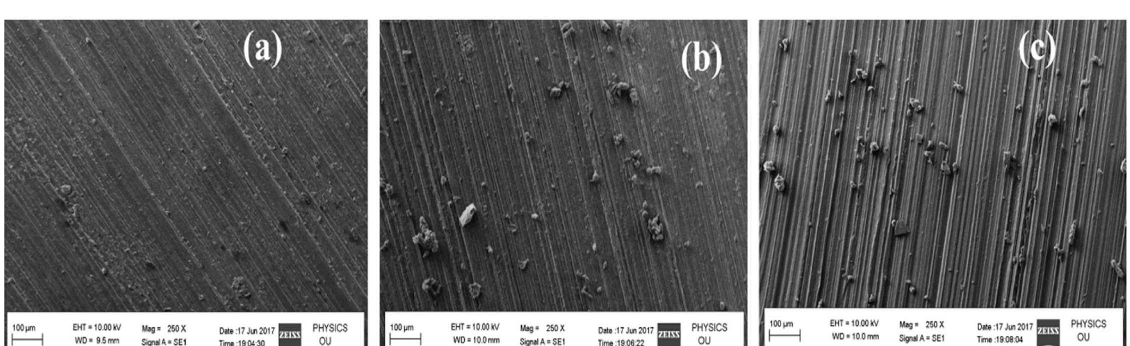

Fig. 7. Worn surfaces of specimens for trial conditions of 1, 2, and 3.

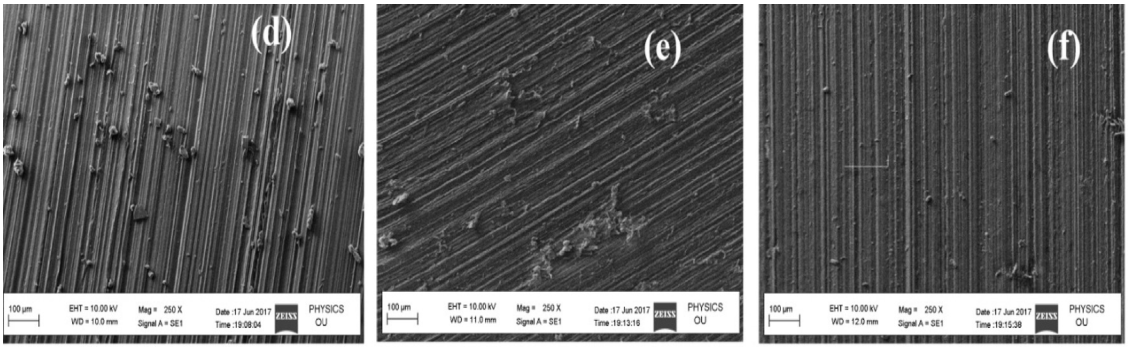

Fig. 8. Worn surfaces of specimens for trial conditions of 4, 5, and 6.

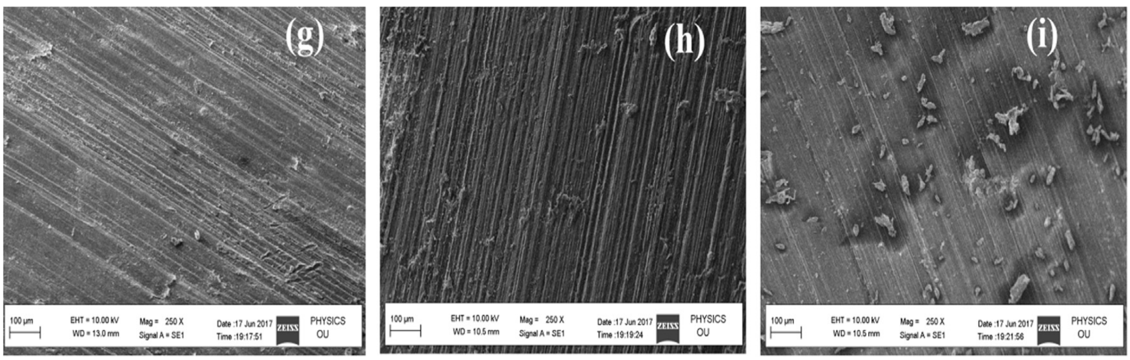

Fig. 9. Worn surfaces of specimens for trial conditions of 7, 8, and 9.

assess wear behavior of Nylon-6/BN polymer composites. The deformation performance of Nylon-6/BNis represented by a considerable dilatational part demonstrating a difference in volume. A definitive quality has diminished with increasing substance of boron nitride in the composites. The flaws were the filler agglomerates or the districts of non-uniform blending in the Nylon-6/BN polymer composites. Radially spreading break development heading lines were the side effects of brittle cracking in the Nylon-6/BN polymer composites. The normal load has presented to impact 71.54% of variety in the wear rate. The wear rate of the composites was additionally expanded as the applied load expanded. As the load and sliding distance were expanded extensive deformation and cracking of the surface were seen in the specimens.

Credit Author Statement

K.Shiva Kumar; Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, A. Chennakesava Reddy; Visualization, Supervision, Project administration.

References

[1] S. Sathees Kumar, G. Kanagaraj, Investigation on mechanical performances of PA6 and Al2O3 reinforced PA6 polymer composites", Int J AdvEngg Tech VII (I) (2016) 69–74.

[2] F. Van De Velde, P. De Baets, The friction and wear behavior of polyamide 6 sliding against steel at low velocity under very high contact pressures, Wear 209 (1) (1997) 106–114.

[3] S. Senthilvelan, R. Gnanamoorthy, Fiber reinforcement in injection molded nylon 6/6 spur gears, Appl. Compos. Mater. 13 (2006) 237–248.

[4] Mohammad M. Hasan, Yuanxin Zhou, Mahfuz Hassan, Shaik Jeelani, Effect of SiO2 nanoparticle on thermal and tensile behavior of nylon-6, Mater. Sci. Eng. 429 (2006) 181–188.

[5] Karan Agarwal, Nirmala Akhil, Regalla Srinivas, A.C. Reddy, Enhancement in mechanical behavior of nylon/teflon composites by addition of nano Iron Oxide (γ-Fe2O3), Int. J. Sci. Res. 4 (5) (2015) 927–932.

[6] Li-Yun Zheng, Kin-Tak Lau, Li-Xin Zhao, Yong-Qiang Zhang, David Huimechanical and thermal properties of nano-AL2O3/NYLON 6 composites, Chem. Eng. Commun. 197 (2010) 343–351.

[7] A.C. Reddy, Characterization of mechanical and tribological behavior of (nylon 6 + graphite + Teflon) nano particulate composite application perspective, Int. J. Sci. Eng. Res. 6 (4) (2015) 378–386.

[8] J. Li, X.H. Sheng, The effect of PA6 content on the mechanical and tribological properties of PA6 reinforced PTFE composites, J. Mater. Eng. Perform. 19 (3) (2010) 342–346.

[9] Bose Suryasarathi, P.A. Mahanwar, Effect of particle size of filler on properties of nylon-6, J. Miner. Mater. Char. Eng. 3 (1) (2004) 23–31.

[10] Yu Seunggun, Do-Kyun Kim, Cheolmin Park, Hong Soon Man, Koo Chong Min, "Thermal conductivity behavior of SiC–Nylon 6,6 and hBN–Nylon 6,6 composites", Res. Chem. Intermed. 40 (2014) 33–40.

[11] O. Fadiran, N. Girouard, J.C. Meredith, Pollen fillers for reinforcing and strengthening of epoxy composites, Emergent Materials 1 (1–2) (2018) 95–103.

[12] Sudhir Kumar, K. Panneerselvam, Research on tribological behaviors of pure and glass fiber reinforced nylon 6 composites against polymer disc, J. Mater. Sci. Mech. Eng. 2 (6) (2015) 24–28.

[13] Li Chang, KlausFriedrich "Enhancement effect of nanoparticles on the sliding wear of short fiber-reinforced polymer composites: a critical discussion of wear mechanisms", Tribol. Int. 43 (2010) 2355–2364.