ELK Asia Pacific Journals – Special Issue
ISBN: 978-81-930411-8-5

OPTIMIZING THE EFFECT OF ADDITION OF MA-G-PE COMPATIBILIZER ON TWO-BODY ABRASIVE WEAR BEHAVIOR OF EVA/HDPE POLYMER BLEND USING TAGUCHI AND ANOVA

Rajeev Namdeo	Smita Manepatil	Sudhir Tiwari	Navin Chand
Department of Mechanical Engineering Shri Vaishnav Polytechnic College Indore-452002, India rrnamdeo@gmail.com	Department of Mechanical Engineering Shri G.S. Institute of Technology & Science Indore-452003, India smita_mp@rediffmail.com	Department of Mechanical Engineering Shri G.S. Institute of Technology & Science Indore-452003, India sudhir2609@gmail.com	Advanced Materials and Processes Research Institute-CSIR Bhopal -462026, Indianavinchand15@yahoo.co.in

***Abstract*— In this study, two-body abrasive wear studies have been carried out on ethylene vinylacetate copolymer/ high-density polyethylene (EVA/HDPE) polymer blends with and without maleic anhydride grafted polyethylene (MA-g-PE). Taguchi L_8 design of experiment is used to measure specific abrasive wear rate under different loads and sliding distances against constant abrasive grade paper in a two body abrasive tester. It was observed that addition of MA-g-PE in polymer blend decreased the immiscibility of EVA and HDPE phases, which improved the wear resistance of compatibilized polymer blend. The addition of 2 phr MA-g-PE in EVA/HDPE polymer blend offered minimum wear volume loss and specific wear rate. Taguchi evaluated optimum combination of phr addition of MA-g-PE with load and sliding distance for minimum abrasive wear. Analysis of variance (ANOVA) exhibited that the sliding distance had great influence on specific wear rate in comparison to modified polymer blend and load. Worn surfaces observed by using SEM explain the same behavior and mechanisms.**

Keywords— Maleic anhydride grafted polyethylene (MA-g-PE); Ethylene vinyl acetate copolymer (EVA); High-density polyethylene (HDPE); Two-body abrasive wear; Taguchi; ANOVA.

I. INTRODUCTION

Polymer blends are becoming popular owing to their tailored properties at low cost in engineering field. Ethylene vinyl acetate (EVA) copolymer is known for its softness, flexibility and good impact strength. It is being used in footwear, seals, caps, car interiors and many industrial applications. In addition, it is being blended with other polymers to enhance its strength and mechanical properties at low cost. Major issue during blending was reported that it is immiscible with other polymers like polyethylene. Low cost, smaller weight-to-strength ratio and good impact resistance made HDPE as the most popular choice in polymer bends. Limited interfacial adhesion between EVA and HDPE

Polymer blend is responsible for poor tribological properties. To improve miscibility of base polymers, compatibilizer is used in immiscible polymer blends. Hamid et al. [1] used HDPE-g-MAH as compatibilizer in blending of polyamide 6/high density polyethylene (PA6/HDPE=70/30 wt%). Rajan et al. [2] studied the effect of compatibilizer on physico-mechanical behaviour EVA/HDPE blends. Bogdanovich et al. [3] studied friction products from the friction on steel of PA-6/HDPE blend, compatibilized HDPE with grafted methylene-butane-dine acid. Ma and Yang [4] developed compatibilized blends of poly(vinylidene fluoride) (PVDF) and thermoplastic polyurethane (TPU) using maleated PVDF (PVDF-g-MA) compatibilizer.

Two-body abrasive wear studies of polymer blends are limited and some of them include development and investigation of mechanical and tribological properties. Ravi Kumar et al. [5] studied two-body abrasive wear behavior of nano-clay filled LDPE/EVA composites with and without poly (ethylene-co-glycidyl methacrylate) compatibilizer. Brostow et al. [6] studied the effects of the presence of Styrene-ethylene/butylene-styrene (SEBS) block copolymer as the compatibilizer on tribological and mechanical properties of PP and PS blends.

Therefore, the aim of this paper is to optimizing the effect of addition of maleic anhydride grafted polyethylene (MA-g-PE) in ethylene vinyl acetate copolymer/high-density polyethylene (EVA/HDPE) polymer blend using Taguchi and analysis of variance (ANOVA).

II. EXPERIMENTAL DETAILS

A. Composition Details

The specimen sheet consists of ethylene vinyl acetate copolymer (EVA: TAISOX 7350 M) and high-density polyethylene (HDPE: HD 50MA 180) polymers with maleic anhydride grafted polyethylene (MA-g-PE: E-156) compatibilizer. The modified polymer blended samples investigated in the present study were procured in the size of 170 x 170 mm^2 and 4 mm thick plates from Council of Scientific and Industrial Research - Advanced Materials and Processes Research Institute, Bhopal. Table I listed the details of the modified polymer blends with their densities. Radium cutter was used to prepare 30 x 50 mm^2 and 4 mm thick specimen samples.

B. Two-Body Wear Test Details

The sample surfaces were cleaned with a soft paper soaked in acetone and thoroughly dried before the conducting the test on two-body abrasion tester as per ASTM D 6037B, principle of which is shown in figure-1 [8]. The sample under test pressed and slides against a rotating wheel (50mm diameter and 12 mm width) covered with carborundum abrasive paper of 50 grade. Experiments were carried out at different loads and sliding distances against abrasive paper. The test sample was initially weighed to an accuracy of 0.1 mg in an electronic balance. The difference between the initial and final weights is the measure of abrasive weight loss. The specific wear rate was calculated as per simple Archard's wear equation.

TABLE I
COMPOSITION DESIGNATIONS WITH THEIR DENSITIES [7]

Polymer	Designation	EVA/HDPE (wt%) MA-g-PE (phr)	Density (gm/cc)
Polymer Blend	PB	70/30/0	0.945
Modified	MPB-1	70/30/1	0.943
Polymer Blend	MPB-2	70/30/2	0.944
	MPB-3	70/30/3	0.945
	MPB-4	70/30/4	0.946

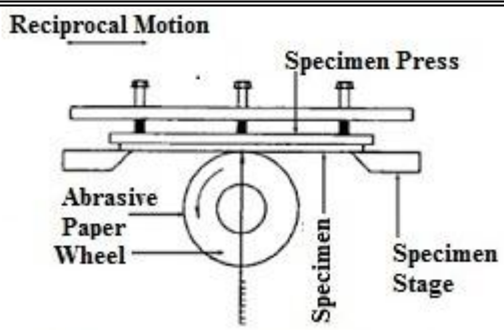
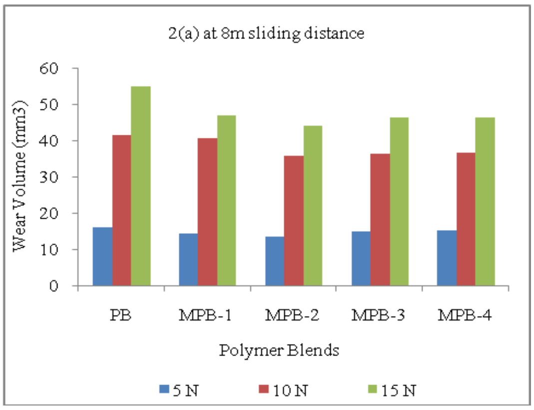


Fig. 1. Principle of Two Body abrasion tester

III. RESULTS AND DISCUSSION

A. Two-Body Wear Volume and Specific Wear Rate

Wear volume loss and specific wear rate in modified polymer blends for 5, 10 and 15N loads at 8 meters sliding distance and for 4, 8 and12m sliding distances at 10N load are shown in figures 2(a-b) and 3(a-b) respectively. Summary of findings of the present study are as below:



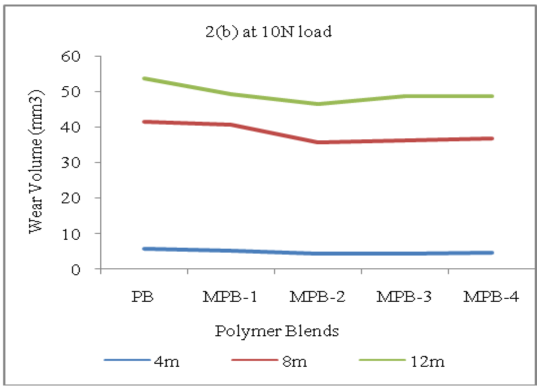
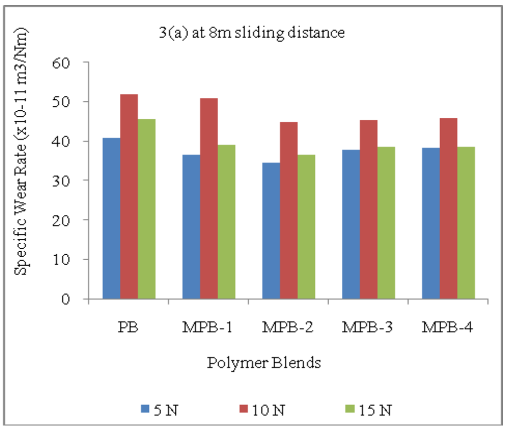


Fig. 2. Wear volume loss versus polymer blends (a) for 5, 10 and 15N loads at 8m sliding distance and (b) for 4, 8 and 12m sliding distance at 10N load.

- Wear volume loss at 8m sliding distance is lowest for 5N load then increases rapidly for 10N load and further for 15N load linear increment is observed as shown in figure 2(a). Similar behaviour of wear volume loss at 10N in figure 2(b) for 4m, 8m and 10m sliding distances is seen.
- Specific wear rate at 8m sliding distances increases from 5 to 10N load, while decreases with further increase of load from 10 to 15N. Variation in specific wear rate is found comparable as shown in figure 3(a).
- Specific wear rate at 10N load varies in broad range as shown in figure 3(b). It is minimum at 4m sliding distance and maximum at 8m sliding distances and decreases from 8m sliding distance to 12m sliding distance.
- All modified polymer blends depict lower wear volume loss and specific wear rate than polymer blend.
- Maximum specific wear rate occurs at 10N load and 8m sliding distance.
- In all the above cases, MPB-2 modified polymer blend has least wear volume loss and specific wear rate.



ISBN: 978-81-930411-8-5

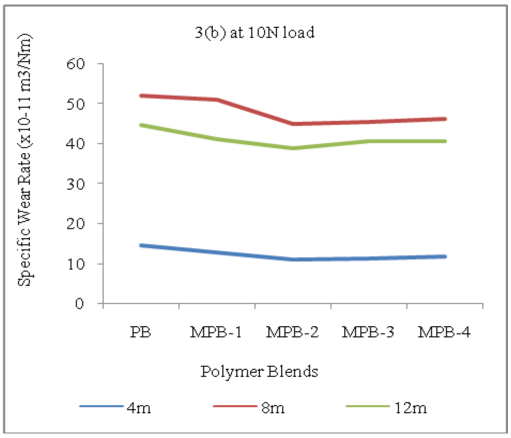


Fig. 3. Specific wear rate versus polymer blends (a) for 5, 10 and 15N loads at 8m sliding distance and (b) for 4, 8 and 12m sliding distance at 10N load.

In the present study, wear volume loss increases sharply from 5N to 10N than 10N to 15N at 8m sliding distance. Low load of 5N is not sufficient to abrade polymer surfaces and highest load of 15N does not contribute much abrasion and causes only slight increase of wear volume loss as compared to abrasion at 10N load. Therefore, at 10N load wear volume loss observed and found that from 4 to 8m sliding distance polymer surface abraded rapidly than from 8 to 12 m sliding distance. Specific wear rate also confirms that at 8m sliding distance, 10N load is responsible for maximum abrasion. At 10N load with varying sliding distance, specific wear rate increases sharply up to 8m sliding distance and then decreases up to 12m sliding distance. This is because up to 8m sliding distance, composites abraded against fresh abrasive grades (single-pass condition), while above 8m sliding distances, composites are abraded against used abrasive grades (multi-pass condition), which is similar to trends reported with LDPE/EVA polymer blends and neat PEEK [5, 9]. Minimum wear volume loss of 35.80 mm^3 and specific wear rate of 44.76 $x10^{-11}$ m^3/Nm for MPB-2 modified polymer blend at 10N load and 8m sliding distance were reported.

B. Taguchi Experimental Analysis

It has been already proven that design of experiments provide the researcher a systematic and efficient way for performing experiments to determine optimum setting of design parameters at low cost without compromising on quality. As shown in table II, Taguchi design of experiments of L_8 orthogonal design with 3 factors, viz, modified polymer blends at 4 levels, laods at 2 levels and sliding distancse at 2 levels is used to calculate specific wear rate with S/N ratio.

Taguchi analysis in table III ranked sliding distance, loads and modified polymer blend as first, second and third on the basis of their effects on specific wear rate.

Main effects plot for S/N ratios, as shown in figure-4, concluded that combination of MPB-2, 15 N load and 200 m sliding distance is an optimum combination for least specific wear rate.

TABLE II
SPECIFIC WEAR RATE AS PER TAGUCHI L_8 EXPERIMENTAL DESIGN

Run	Modified Polymer Blend	Load (N)	Sliding Distance (m)	Sp. Wear Rate ($x10^{-11}$ m^3/Nm)	S/N Ratio (db)
1	MPB-1	10	4	12.72	-22.09
2	MPB-1	15	8	39.06	-31.83
3	MPB-2	10	4	10.86	-20.71
4	MPB-2	15	8	36.63	-31.28
5	MPB-3	10	8	45.37	-33.13
6	MPB-3	15	4	8.99	-19.08
7	MPB-4	10	8	45.98	-33.25
8	MPB-4	15	4	9.34	-19.40

TABLE III
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS

Level	Modified Polymer Blend	Load (N)	Sliding Distance (m)
1	-26.96	-27.30	-20.32
2	-26.00	-25.40	-32.37
3	-26.11		
4	-26.33		
Delta	0.97	1.90	12.05
Rank	3	2	1

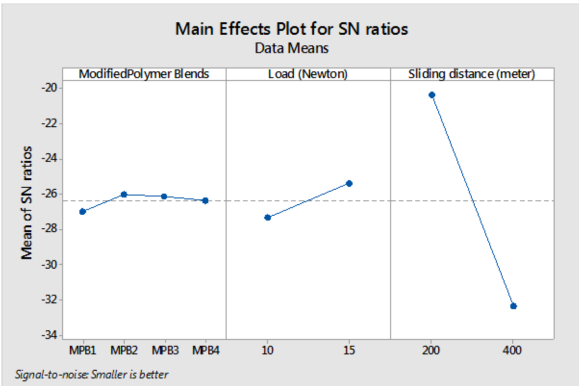


Fig. 4. Main effects plot for S/N ratios.

C. ANOVA Analysis

General linear model with factor coding -1, 0 and +1 at 95% confidence level or 5% significance level is used in analysis of variance. ANOVA is performed on experimental data to find out statistical significance of composite combinations, normal load and sliding distance factors on specific wear rate using MINITAB software. Table IV shows the results of the ANOVA for the specific wear rate of polymer blends.

It was observed that calculated F (1, 7) and (3, 7) are much more than tabulated F value 5.59 and 4.35 respectively and also P value is less than 0.05 for all 3 factors at 95% confidence level or 5% significance level. Therefore, all three factors are significant. Percentage contribution of the control factors in the last column of the table indicated that sliding distance (96.4%) has great significant contribution while modified polymer blends (0.9%) and load (2.7%) have less influence on specific wear rate. Yousif et al. [10] found that sliding distance play major role in influencing the wear characteristics of composites, which support the significant contribution of sliding distance in modified polymer blends.

TABLE IV
ANOVA TABLE FOR SPECIFIC WEAR RATE

Source	DF	Adj. SS	Adj. MS	F- Value	P-Value	% Cont.
MPB	3	18.37	6.12	127.69	0.008	0.9
Load (N)	1	54.65	54.65	1139.48	0.001	2.7
Sliding Dist. (m)	1	1957.26	1957.26	40807.19	0.000	96.4
Error	2	0.10	0.05			
Total	7	2030.39				100.0

D. Confirmation Test

A prediction of specific wear rate for arbitrary set of factor combinations MPB-2, 15N and 4m is selected, which is shown in table V.

The confirmation experiment was performed and experimental value of specific wear rate is compared with the predicted value to calculate percentage error. An error of 3.9% is well within the reasonable limits. Therefore, predicted value is proven reliable and testified the validity of this predictive model.

E. Scanning Electron Microscopy

TABLE V
RESULT OF THE CONFIRMATION EXPERIMENT

Control factor Combinations	Specific Wear Rate ($x10^{-11}$ m^3/Nm)		
	Predicted	Experimental	Error (%)
MPB-2, 15 N, 4 m	8.45	8.12	3.9

Polymer wear may be subjected to microcracking, microcutting, microploughing and microfatigue wear mechanism or combination of them [11]. With the increase of MA-g-PE compatibilizer in modified polymer blends, worn surfaces are shown in figures 5 (a) to (d).

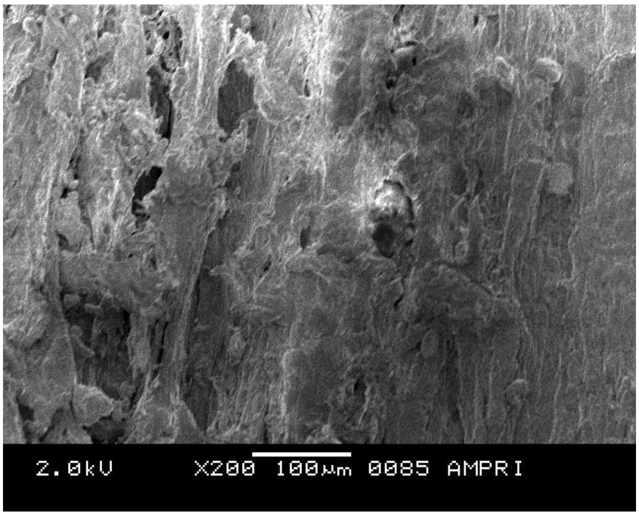


Fig. 5(a). MPB-1 at 8 m distance and 10N load

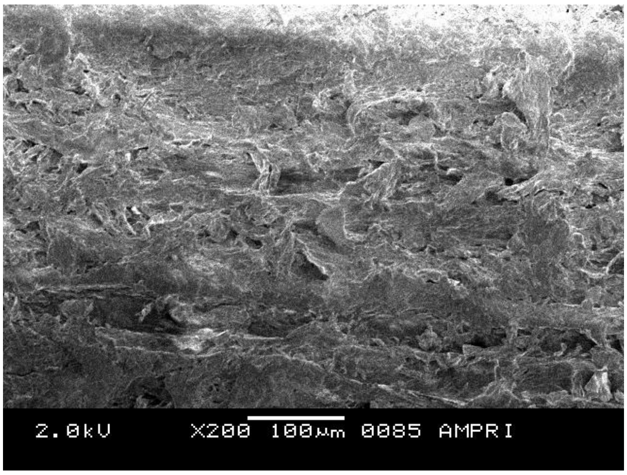


Fig. 5(b). MPB-2 at 8 m distance and 10N load

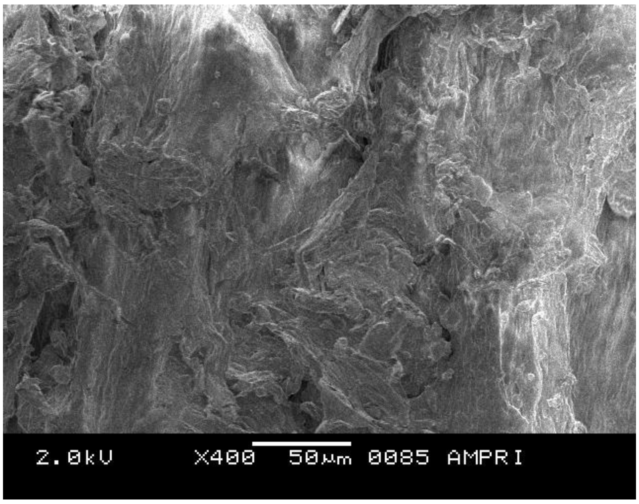


Fig. 5(c). MPB-3 at 12 m distance and 10N load

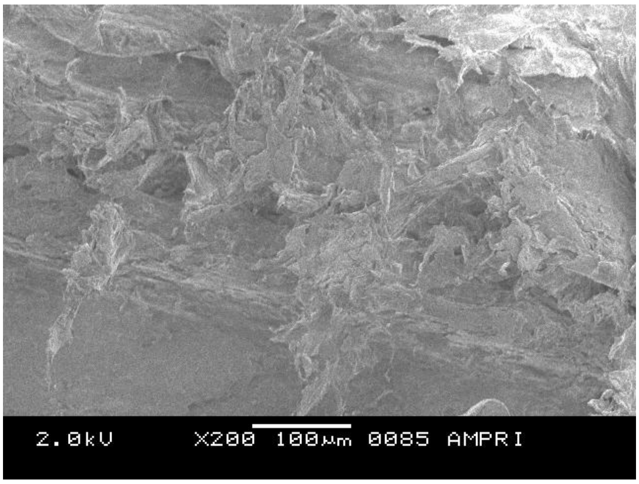


Fig. 5(d). MPB-4 at 4m distance and 10N load

Fig. 5(a-d). Scanning electron micrographs of modified polymer blends with compatibilizer (EVA/HDPE/MA-g-PE).

Surfaces of modified polymer blends were changed to soft rubbery nature with the addition of compatibilizer. Softness in structure changed the wear mechanisms from microcracking plastic deformation to microploughing plastic deformation. Polypropylene (PP) and polystyrene blends (PS) with styrene-ethylene/butylene-styrene (SEBS) block copolymer compatibilizer and LDPE/EVA polymer blend with MA-g-PE compatibilizer shown similar trends [5, 6]. Among all discussed modified polymer blends, comparatively less surface matrix damage in two-body abrasion observed in MPB-2 at 8m distance and 10N load.

IV. CONCLUSIONS

A two-body abrasive wear experimental study to optimize the effect of addition of maleic anhydride grafted polyethylene (MA-g-PE) in ethylene vinyl acetate copolymer/high-density polyethylene (EVA/HDPE) polymer blend using analysis of variance unveils the following characteristics:

- In EVA/HDPE/MA-g-PE modified polymer blends, MPB-2 (70/30/2) has least wear volume loss and specific wear rate at all loads and sliding distances.
- Maximum wear volume loss and specific wear rate occur at 10N load and 8m sliding distance in all polymer composites.
- Main plots for S/N ration in Taguchi experimental design shown that combination of MPB-2, 15 N load and 200 m sliding distance is an optimum combination for least specific wear rate.
- Analysis of variance at 95% confidence level or 5% significance level concluded that sliding distance (P = 96.40%) have great influence on specific wear rate of polymer composites than the other two control factors.
- Both Taguchi and ANOVA concluded that sliding distance has great influence on specific wear rate.
- SEM images of worn surfaces revealed that addition of addition of MA-g-PE compatibilizer in EVA/HDPE polymer blend reduced surface matrix damage and changed the wear mechanisms from microcracking plastic deformation to microploughing plastic deformation.

Acknowledgment

Authors would like to the acknowledge faculties, staffs and students of AMPRI-CSIR Bhopal for their valuable and unconditional supports during this experimental research work.

References

[1] F. Hamid, S. Akhbar, K.H. Ku Halim, Mechanical and Thermal Properties of Polyamide 6/HDPE-g- MAH/High Density Polyethylene, Procedia Engineering 68 (2013) 418-424.

[2] A. Rajan, P. Upadhyaya, N. Chand, V. Kumar, Effect of compatibilizer on physico-mechanical behavior of poly (ethylene-co-vinyl acetate) / High Density Polyethylene Blends, National Conference on Advanced Polymers, Fibers and Fabrics, Kanpur (India) 26-28 December 2011.

[3] S. P. Bogdanovich, Yu. A. Ollkhov, S. S. Pesetskii, Thermomechanical spectrometry of friction products formed in friction of compatibilized PA-6/HDPE blend with steel, Journal of friction and wear, 29-6 (2008) 423-433.

[4] H. Ma, Y. Yang, Rheology, morphology and mechanical properties of compatibilized poly(vinylidene fluoride) (PVDF)/thermoplastic polyurethane (TPU) blends, Polymer Testing 27 (2008) 441–446

[5] B. N. Ravi Kumar, M. Venkataramareddy, B. Suresha, Two-body abrasive wear behavior of nano-clay filled LDPE/EVA composites, Journal of Reinforces Plastics and Composites 28-24 (2009) 2999-3007.

[6] W. Brostow, T. H. Grguric, O. Olea-Mejia, D. Pietkiewicz,V. Rek, Polypropylene + Polystyrene Blends with a Compatibilizer (Part 2), Tribological and Mechanical Properties, e-polymers (2008).

[7] A. Rajan, Development of MA-g-PE modified EVA/HDPE nanocomposites and their mechanical, thermal and moisture absorption behaviour, M. Tech. Thesis, Gautam Buddh Technical University Lucknow, India, (2011).

[8] ASTM D6037-13e1, Standard Test Methods for Dry Abrasion Mar Resistance of High Gloss Coatings, ASTM International, West Conshohocken, PA (2013).

[9] A. P. Harsha, U. S. Tewari, Two-body and three-body abrasive wear behaviour of polyaryletherketone composites, Polymer Testing, 22 (2003) 403–418.

[10] B.F. Yousif, U. Nirmal, K. J. Wong, Three-body abrasion on wear and frictional performance of treated betelnut fibre reinforced epoxy (T-BFRE) composite, Materials and Design 31 (2010) 4514–4521.

[11] K.H. Zum Gahr, Wear by hard particles, Tribology International 31 (1998) 587–596.