Characteristics of wear resistanceand hardness investigation of graphite powder filler and Kevlar fiber reinforced polypropylene matrix composites – A Taguchi's Approach.

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Abstract:

In this work the attempt is made to investigate the importance of reinforcements like graphite powder at various percentages in the polypropylene matrix to evaluate the tribo-mechanical properties of the composites developed. The graphite powder is reinforced in multiple weight fraction i.e 3%, 5% and 7% along with a 30% reinforced Kevlar fibers. For the uniform mixing of the fillers and fibers, twin screw extrusion method was involved followed by the hot compression molding. The various weight factions of the composites developed were taken for the tribological tests. Pin on disc machine rig is used to conduct the tribological study as per the ASTM standards. Design of experiment was adopted to know the optimal level of the wear rate. Minitab software is used to know the multiple interactions between the composites and their factors. The load applied on the pin on the disc at various levels, the rotation of the disc at different speed and the weight fraction of the composites are considered as the factors. Also, the shore D hardness of the composites was investigated as per the ASTM standards. From the investigation it is concluded that higher the percentage of reinforcement of the graphite powder the wear resistance will be high. Also the presence of Kevlar fiber in the composites helped in enhancing the wear rate of the composites. The 7% presence of the graphite powder composites is able to perform better w.r.t hardness test.

Keywords: Polymer composites, Tribology, Design of experiments, Kevlar fibers, Graphite Powder.

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Introduction:

Additive manufacturing industry has gained a huge boost introducing polymer-fiber composite enabling production of complex customized design parts having remarkable mechanical properties as compared to un-reinforced polymers [1-4]. In this project, Kevlar fibers were added as reinforcement layer to polypropylene along with graphite powder fillers to enhance the tribo-mechanical properties of the composite. The investigation on the hardness properties of polypropylene composites, that consists of different wt% of fibers and fillers. Kevlar fiber (KF) and graphite powder are used as reinforcement in the polypropylene (PP) matrix. Three different composites were composed with varying wt% of graphite powder (3%, 5% and 7%)

along with a fixed wt% of KF (30%). For the preparation of the PMC twin screw extruder is used for consistent blend of the reinforcement and the matrix subsequently compression molding is performed. Kevlar fiber had properties such as high tensile strength, high stability, high chemical strength; polypropylene has rigidity, good impact strength, wear resistance, graphite powder has high thermal expansion, high thermal insulation, all this property has gained attention for application of this materials in material science, and so the preparation of combination of these materials was done to obtain a composite [5-8]. The main objective of this work to identify the change in characteristics of the composites as the change in composition of graphite powder filler. Shore D Hardness test is performed on the prepared composites as per the ASTM standards. The investigative result shows that the PMC having a composition of 7% of graphite powder is having the properties that we desire to use; other 2 composites have lower hardness strength. This sample composite has enhanced its hardness to 12% as compared to composite sample 1 and by 40.57% as compared to composite sample 3; by having just a minute change in hardness compared to other composite samples. The table 1.1 gives the percentage composition of all the three composites used in this investigation.

Materials and Preparation:

The composites in this investigation are prepared with the help of Twin screw extruder. Initially the Kevlar fibres for chapped for 1mm to 2 mm in length and then the predefined weight fraction of the graphite powders are taken in and fed into the Twin screw extruder along with the polypropylene granules[9-12].The Twin screw extruder is heated up to 160 degree temperature so that the polypropylene Matrix will melt and meanwhile the extruder will help in uniform mixing of the pillars and the fibres as per the predefined weight fraction the graphite powder are fed in three stages one is 3% 5% and 7% keeping the kevlar fibre weight fraction constant that is 30% after the Twin screw extrusion the mixture is taken for the hot compression moulding as per the ASTM standards. The detailed weight percentage composition of the composites is given in the table 1.1.

Table 1.1. Percentage composition of the composites

Sl Number	Composite Abbreviation	Weight Percentage of Polypropylene	Weight percentage of Kevlar	Weight percentage of Graphite powder
1	C1	67%	30	3
2	C2	65%	30	5
3	C3	63%	30	7

Taguchi Design:Taguchi Orthogonal Array Design

The L16 orthogonal array L16(4**3), four factors and three levels design of experiment approach was included for the current study. Factors such as weight composition of the composites, load applied on the pin during the wear test and speed of the rotation of the disc. Also, w.r.t levels, the composites weight fraction has three levels, load of 5N, 10N and 15N and the speed of disc rotation at 200RPM, 400RPM and 600RPM was implemented followed by the pilot tests.

Table 1.2: Taguchi Analysis: WEAR RATE versus COMPOSITES, SPEED OF THE, LOAD ON THE PIN, Estimated Model Coefficients for SN ratios

Term	Coef SE	Coef	T	P
Constant	-62.539	0.0162	-3860.9	0
COMPOSIT C1	0.6561	0.02806	23.386	0
COMPOSIT C2	0.2271	0.02806	8.095	0

COMPOSIT C3	-0.2501	0.02806	-8.913	0
SPEED OF 200	0.6825	0.02806	24.325	0
SPEED OF 400	0.2526	0.02806	9.002	0
SPEED OF 600	-0.2346	0.02806	-8.362	0
LOAD ON 5	0.0142	0.02806	0.506	0.631
LOAD ON 10	-0.0776	0.02806	-2.767	0.033
LOAD ON 15	-0.0508	0.02806	-1.812	0.12

S = 0.06479 R-Sq = 99.7% R-Sq(adj) = 99.2%

Table 1.3: Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
COMPOSITES	3	3.78206	3.78206	1.26069	300.3	0
SPEED OF THE DISC ROTATION	3	4.3007	4.3007	1.43357	341.49	0
LOAD ON THE PIN	3	0.08749	0.08749	0.02916	6.95	0.022
Residual Error	6	0.02519	0.02519	0.0042		
Total	**15**	**8.19544**				

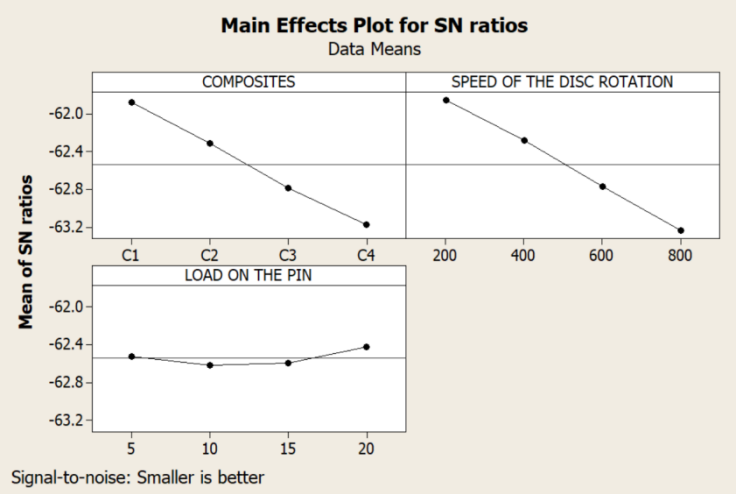

Figure 1.1 Main effects plots for signal to noise

It is observed that from the wear test, when the weight percentage of the graphite powder is increased from 3% to 7%, the wear resistance of the composites also increasing. This is also supported by the Kevlar fibers. Even on the higher load and rotation of the disc the highest weight percentage of graphite powder composites are able to resist wear and friction[13-15]. Whereas, the lowest graphite powder weight percentage composites are losing more over higher load and speed.

Table 1.4: Linear Model Analysis: Means versus COMPOSITES, SPEED OF THE, LOAD ON THE PIN: Estimated Model Coefficients for Means

Term	Coef SE	Coef	T	P
Constant	1344.06	3.019	445.228	0
COMPOSIT C1	-100.3	5.229	-19.185	0
COMPOSIT C2	-36.81	5.229	-7.04	0
COMPOSIT C3	37.69	5.229	7.208	0
SPEED OF 200	-104.06	5.229	-19.902	0
SPEED OF 400	-41.06	5.229	-7.853	0
SPEED OF 600	34.19	5.229	6.538	0.001
LOAD ON 5	1.94	5.229	0.371	0.724
LOAD ON 10	15.19	5.229	2.905	0.027
LOAD ON 15	4.94	5.229	0.944	0.381

S = 12.08 R-Sq = 99.6% R-Sq(adj) = 98.9%

Three different set of composites are used for each tests. The average of the three sets of composites for wear tests is considered. The mentioned values are tabulated for the further analysis in Minitab 16.

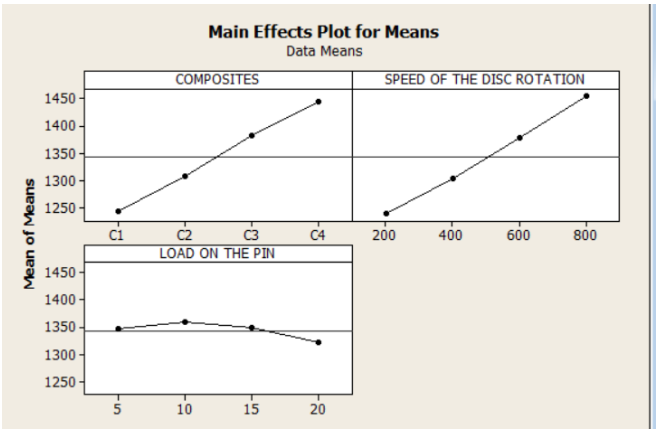

Figure 1.2. Main effects plots for means

Table 1.5: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
COMPOSITES	3	90904	90904	30301.2	207.81	0
SPEED OF THE DISC ROTATION	3	103964	103964	34654.7	237.67	0
LOAD ON THE PIN	3	2982	2982	994.1	6.82	0.023
Residual Error	6	875	875	145.8		
Total	15	198725				

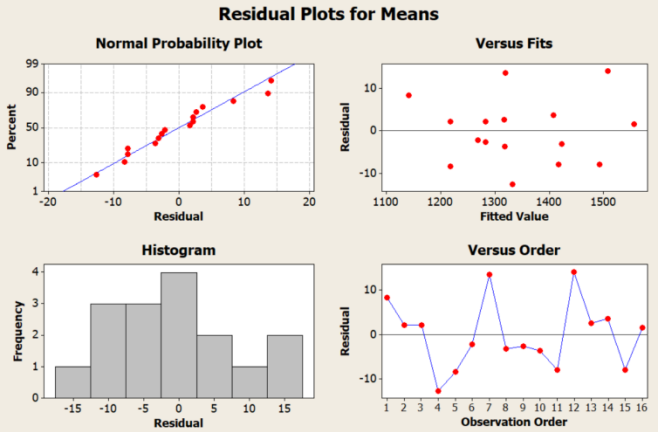

Figure 1.3: Residual plots for means

The 99.6% R square value of the from the ANOVA indicates the accuracy of the test conducted. Also, normal probability plot scatter diagram shows how accurate the experiment investigation conducted.

Table1.6: Response Table for Signal to Noise Ratios: Smaller is better

LEVEL	COMPOSITES	SPEED OF DISC	LOAD ON THE PIN
1	-61.88	-61.86	-62.52
2	-62.31	-62.29	-62.62
3	-62.79	-62.77	-62.59
4	-63.17	-63.24	-62.42
Delta	1.29	1.38	0.19
Rank	2	1	3

Table 1.7: Response Table for Means

LEVEL	COMPOSITES	SPEED OF DISC	LOAD ON THE PIN
1	1244	1240	1346
2	1307	1303	1359
3	1382	1378	1349
4	1444	1455	1322
Delta	200	215	37
Rank	2	1	3

From the response table for signal to noise ratio and means, it is clearly observed that the speed of disc rotation is playing a vital role with respect to wear rate. The weight percentage of composites and load on the pin are found to be contributing after the disc rotation speed. The analysis is done by considering smaller the better characteristics.

Shore D hardness: Mechanical test

Table 1.8: Share D hardness of developed composites

Sl no.	Composites	Shore D Hardness
1	C1	81
2	C2	86
3	C3	90

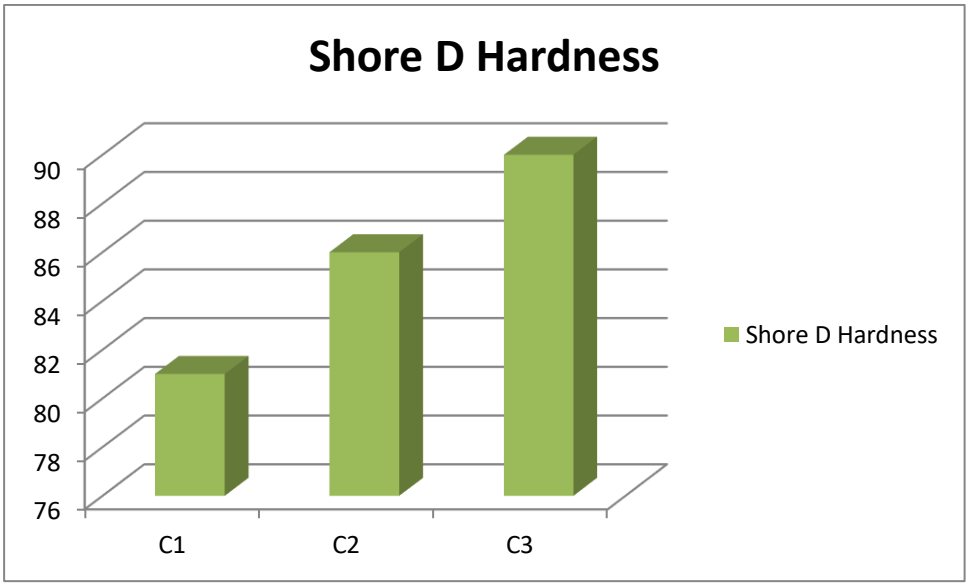

Figure 1.4: Shore D hardness values of C1, C2 and C3 composites.

The Shore D hardness investigation was conducted as per ASTM standards [16-18]. Three replicates of each composite were taken for hardness test. From the hardness test results it is observed that C3 composites which are rich in graphite powder content are able to withstand more amount of load applied. C3 composites shore D hardness value is found to be 90, followed by C2 and C1, which are 86 and 81 respectively.

Conclusion

From the tribo-mechanical investigation it is observed that, the composites are able to withstand more load and speed this is due to presence of Kevlar fiber. The twin screw extrusion helped in proper mixing of the fillers and the fibers. So from the investigation it is found that when the graphite weight fraction is increased by 3% to 5% and 5% to 7%, the wear resistance of the composites are good. This is due to the self-lubrication property of the graphite powder. Also, as Kevlar fibers are kept constant for 30% in all composites, they also able to contribute towards withstanding higher load and speed during pin on disc testing. The 7% weight fraction of the graphite powder i.e. C3 composites found to be harder in comparison with C1 and C2 composites.

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