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Study of tribological properties of ABS / $CaCO_3$ polymer composites using Taguchi method

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ABSTRACT: *In this paper, acrylonitrile – butadiene – styrene (ABS) with different compositions of micron-sized $CaCO_3$, composite material is prepared by compression moulding through melt compounding. The tribological properties (friction and wear depth) of the polymer composites are investigated in a multi-tribo-tester using block-on-roller configuration in dry sliding conditions for a time of 300 seconds at ambient temperature. Experiments are conducted based on L_{27} orthogonal array considering three design parameters viz. filler content, normal load and sliding speed. The experimental data are analysed using Taguchi method. Optimal settings of the process parameters are found out for coefficient of friction and wear depth. ANOVA is carried out to obtain the significant factors affecting friction and wear depth. It is seen that normal load is the main significant factor affecting wear at 95% confidence level. Confirmation tests for coefficient of friction and wear are carried out to validate the optimized results and it is seen that there are improvements in S/N ratios from initial to optimal setting. Finally, the wear tracks of the composite are observed on a scanning electron microscope (SEM).*

Keywords: *Composite material, Friction coefficient, Optimization, Taguchi method, Wear depth.*

I. INTRODUCTION

Nowadays polymers are widely used in various tribological components due to the advantage of self-lubrication. But polymers alone cannot satisfy the required properties for tribological applications. Thus, in order to improve properties and to lower the cost of polymer products, inorganic particulate fillers are employed. ABS (Acrylonitrile – butadiene – styrene) is a well known engineering thermoplastic terpolymer over the past decades. The acrylonitrile gives chemical resistance and heat stability, butadiene gives toughness and impact strength and the styrene gives rigidity and easiness of processability. Inorganic particulate fillers of micrometer-sized particles can improve modulus, hardness and fracture toughness but at the cost of reduced impact strength and tensile strength in the polymer composites [1-4].

Polymer composites can be effective if the right combination of filler with matrix and the suitable production process are used in order to achieve the special properties [5]. In particular, polymers containing fillers have been widely used in various applications. But there has been little investigation on the development of ABS polymer with micro-sized $CaCO_3$ conventional filler for tribological applications. Most of the literatures are based on the mechanical properties of ABS / $CaCO_3$ composites. Jiang et al. [2] found that micron sized filler is more effective in terms of modulus than nano-sized $CaCO_3$. Tang et al. [3] and Liang [4] have studied tensile, impact and bending properties of $CaCO_3$ and hollow glass bead filled ABS. For injection molded specimens, the tensile modulus increases with increase in the ratio of fillers and tensile strength decreases gently with the increase of filler. Difallah et al. [5] observed that the tensile modulus and strength decrease but friction decreases with an increase in content of graphite for ABS/graphite composite. Shenavar et al. [6] have reported that modulus increases and yield stress decreases by increasing the carbon black loading. Henshaw et al. [7] and Chuyjulijit and Ketthongmongkol [8] have reported that the injection moulded specimens exhibit good mechanical properties like tensile strength and elongation at break. In order to improve the wear resistance, various kinds of fillers such as TiO_2, ZrO_2, CuO, CuS, $CaCO_3$ are used with various polymers [9-10].

From the review of literatures, it is seen that ABS / $CaCO_3$ composites have received limited attention compared to other engineering thermoplastics in the tribological field. The present study is focussed on the tribological behaviour of ABS / $CaCO_3$ composites. The friction and wear performance of the polymer composites are investigated under different filler content, normal load and sliding speed with the constant time of 300 seconds based on L_{27} orthogonal array. The experimental data is analysed using Taguchi method to find the optimal setting of the process parameters for minimum wear and friction. Also, ANOVA is carried out to obtain the significant factors affecting wear and friction. Confirmation tests are carried out to validate the study. Finally, an effort is made to study the morphology of wear tracks after the tribological tests using SEM images.

II. EXPERIMENTAL DETAILS

The matrix chosen in this study is commercially available acrylonitrile-butadiene-styrene (ABS) pellets (Absolac – 920 Bayer), high flow medium impact grade with a density of 1.04 g/cm^3. Calcium carbonate ($CaCO_3$) manufactured by Gulsan Polyol Ltd, India with a mean particle size of 2 – 2.5 µm is used as filler. ABS/$CaCO_3$ composites in different compositions of 5, 10 and 15 wt% fillers are prepared using hot compression molding process. Then friction and wear tests are performed on a block on roller multi-tribotester TR25 (Ducom, India) in dry condition and at ambient temperature of 28 °C. The composite samples (20 X 20 X 8 mm^3) are pressed against a rotating steel roller (diameter 50 mm, thickness 50 mm and material EN8 steel) of hardness 55 HRc. The rotating steel roller serves as a counter face and the stationery block serves as the test specimen. Three design parameters viz. filler content, normal load and sliding speed are considered in the present study and total 27 experiments are carried out based on L_{27} orthogonal array (OA) of Taguchi method. Table 1 presents the design factors with their levels. For different combinations of these design factors, coefficient of friction and wear depth (in µm) are measured directly in the experimental setup.

Table 1. Design factors with different levels.

Design factors	Unit	Levels		
		1	2	3
% of filler (A)	%	5	10	15
Load (B)	N	15	25	35
Speed (C)	rpm	80	100	120

SEM examinations of wear surfaces are carried out on a scanning electron microscope, JEOL, Japan (Model- JSM 6390LV) to observe the morphology of wear tracks and the dispersion morphology of $CaCO_3$ filler and its interactions with the ABS polymer matrix.

III. RESULTS AND DISCUSSION

3.1 Taguchi analysis for friction and wear depth

Experimental results for coefficient of friction (COF) and wear are presented in Table 2. Taguchi method [11] is employed to analyze the experimental data. Since, smaller values of testing results are required, so lower-the-better (LB) criterion is selected here to find out the signal to noise (S/N) ratio. S/N ratio for each combination of parameters is calculated and presented in Table 2. Analyses of the influence of each control factor (A, B, C) on the responses are obtained from the response tables of mean S/N ratio and shown in Table 3 and Table 4 for friction and wear respectively. The main effects plots for S/N ratios are presented in Fig. 1 and Fig. 2 for coefficient of friction and wear depth respectively. Larger value of S/N ratio corresponds to better quality, so the optimal combination of design parameters can be obtained as A1B3C3 for coefficient of friction and A2B1C2 for wear depth.

3.2 Analysis of Variance (ANOVA)

ANOVA is carried out to find out the significance of process parameters on the quality characteristics and also the percentage contributions of the factors and the interactions affecting the response. The percentage calculations are done by the total sum of squared deviations from the total mean S/N ratio. ANOVA tables for coefficient of friction and wear are shown in Table 5 and Table 6 respectively. It is seen that the most significant factor for coefficient of friction is normal load (B) at 95% confidence level (Table 5). For wear, at 95% confidence level, no parameter is significant but considering the contribution of the influences, the interaction between load and speed (B*C) is the most influential followed by filler content and load (A*B) (Table 6).

3.2 Confirmation test

To validate the experimental results and to evaluate the accuracy of the analysis, confirmation tests are performed. The comparisons of the estimated and the actual COF and wear are shown in Table 7 and Table 8 respectively. The improvements of S/N ratios for coefficient of friction and wear from initial to optimal condition are 4.0346 dB (31.46%) and 12.3103 dB (32.95%) respectively.

Table 2. Experimental results of COF and wear along with S/N ratios

Trial No.	COF	Wear (µm)	S/N ratio (COF)	S/N ratio (Wear depth)
1	0.2919	71.721	10.6953	-37.1129
2	0.227	100.44	12.8795	-40.0381
3	0.2185	81.203	13.2110	-38.1914
4	0.2372	43.961	12.4977	-32.8614
5	0.2697	70.053	11.3824	-36.9085

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6	0.1695	75.292	15.4166	-37.5350
7	0.1886	87.776	14.4892	-38.8675
8	0.2157	73.274	13.3230	-37.2990
9	0.1436	41.708	16.8569	-32.4044
10	0.2279	27.012	12.8451	-28.6311
11	0.2013	17.883	13.9231	-25.0488
12	0.2724	64.986	11.2959	-36.2564
13	0.3706	76.165	8.6219	-37.6351
14	0.2285	73.783	12.8223	-37.3591
15	0.278	65.371	11.1191	-36.3077
16	0.2262	100.548	12.9101	-40.0475
17	0.1725	58.983	15.2642	-35.4145
18	0.2207	52.055	13.1240	-34.3292
19	0.3485	53.109	9.1559	-34.5034
20	0.2678	41.817	11.4438	-32.4271
21	0.31	68.101	10.1728	-36.6631
22	0.2068	61.026	13.6890	-35.7103
23	0.2638	121.415	11.5745	-41.6854
24	0.2515	51.85	11.9892	-34.2950
25	0.2107	72.488	13.5267	-37.2053
26	0.1854	44.926	14.6378	-33.0500
27	0.1902	92.179	14.4158	-39.2926

Table 3. Response table of mean of S/N ratio for COF

Level	A	B	C
1	13.42	11.74	12.05
2	12.44	12.12	13.03
3	12.29	14.28	13.07
Delta	1.13	2.55	1.02
Rank	2	1	3

Table 4. Response table of mean of S/N ratio for wear

Level	A	B	C
1	-36.8	-34.32	-35.84
2	-34.56	-36.7	-35.47
3	-36.09	-36.43	-36.14
Delta	2.24	2.38	0.67
Rank	2	1	3

Table 5. ANOVA results for coefficient of friction

Factors	DF	SS	MS	F	P	Contribution %
A	2	0.00488	0.00244	1.7	0.242	6.64
B	2	0.024248	0.012124	8.46	0.011	33.01
C	2	0.005244	0.002622	1.83	0.221	7.14
A*B	4	0.013068	0.003267	2.28	0.149	17.79
A*C	4	0.011643	0.002911	2.03	0.183	15.85
B*C	4	0.002909	0.000727	0.51	0.732	3.96
Error	8	0.011458	0.001432			15.60
Total	26	0.073451				

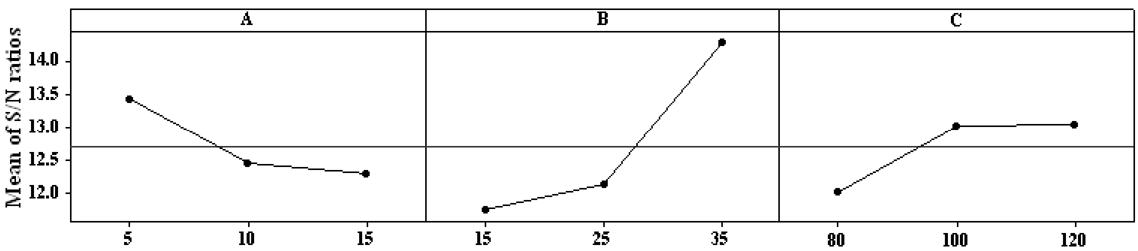


Fig. 1 Main effect plot for S/N ratio of COF

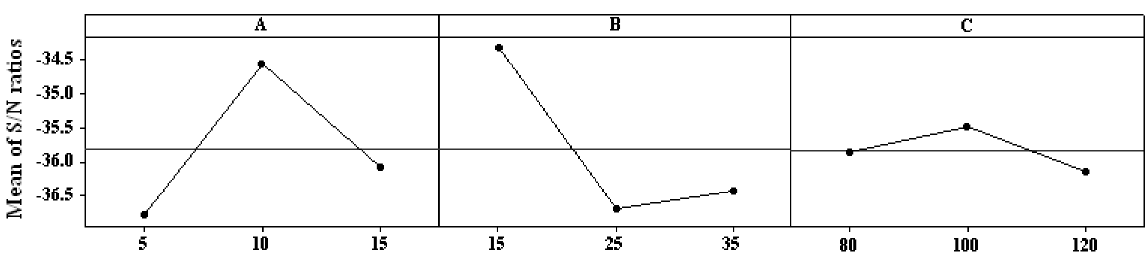


Fig. 2 Main effect plot for S/N ratio of wear depth

Table 6. ANOVA results for wear depth.

Source	DF	SS	MS	F	P	Contribution %
A	2	674.2	337.1	0.59	0.575	4.88
B	2	831.5	415.8	0.73	0.511	6.02
C	2	6.5	3.2	0.01	0.994	0.05
A*B	4	3188.2	797	1.4	0.316	23.08
A*C	4	1009	252.2	0.44	0.775	7.30
B*C	4	3556.8	889.2	1.56	0.273	25.75
Error	8	4548.3	568.5			32.92
Total	26	13814.4				

Table 7. Confirmation test results for COF

	Initial parameter	Optimal parameter	Experimental
Level	A2B2C2	A1B3C3	A1B3C3
COF	0.2285		0.1436
S/N ratio	12.8223	15.3300	16.8569
Improvement of S/N ratio=4.0346 dB (31.46%)			

Table 8. Confirmation test results for wear

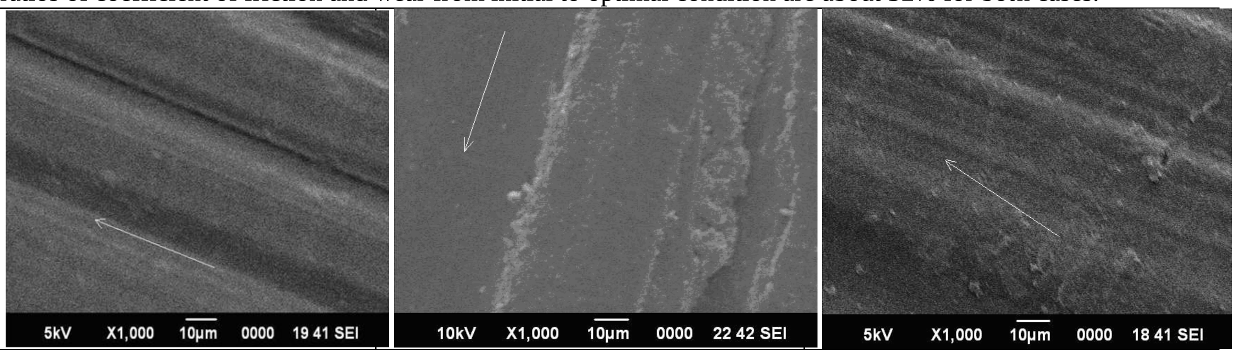
	Initial parameter	Optimal parameter	Experimental
Level	A2B2C2	A2B1C2	A2B1C2
Wear(μm)	73.783		17.883
S/N ratio	-37.3591	-32.7167	-25.0488
Improvement of S/N ratio=12.3103 dB (32.95%)			

3.3 Scanning electron microscopy

SEM images are used to investigate the wear mechanisms with different filler compositions after the tribological tests and shown in Fig. 3 (a-c). It is observed that the worn surface is mainly composed of longitudinal grooves along the sliding direction. It is also seen that the dispersion of filler with the matrix is even throughout the surface. The arrow marks in the SEM images show the sliding directions. Micro-cutting effects are dominant and the composite undergoes abrasive wear.

IV. CONCLUSION

The tribological properties of ABS / $CaCO_3$ micron-sized composites prepared by compression molding process through melt compounding are investigated in this study. Friction and wear experiments are conducted in a multi-tribo-tester using block-on-roller configuration in dry sliding conditions for a time of 300 seconds with three different levels of filler content, normal load and sliding speed. Optimizations of friction and wear test parameters are done with the help of Taguchi analysis. It is seen form ANOVA that normal load (B) is the most significant factor affecting friction coefficient. The confirmation tests show the improvements of S/N ratios of coefficient of friction and wear from initial to optimal condition are about 32% for both cases.



(a) 5wt% of fillers	(b) 10wt% of fillers	(c) 15wt% of fillers

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