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Study of tribological behavior of ABS/ $CaCO_3$ composite using grey relational analysis

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Abstract

The tribological properties of acrylonitrile-butadiene-styrene (ABS) polymer filled with micron-sized calcium carbonate ($CaCO_3$) are studied in this paper. Filler content, normal load and sliding speed are considered as design parameters and coefficient of friction (COF) and specific wear rate are considered as the responses. The experiments are conducted on multi-tribotester (block-on-roller configuration) based on L_{27} orthogonal array (OA). The optimum design parameter combination for minimum coefficient of friction and specific wear rate are found using grey relational analysis. The optimum parameter combination is found to be 5% of filler content, 35 N of load and 120 rpm of speed. Analysis of variance (ANOVA) is also used to find out the most influential factor which affects the tribological properties. The most influential factor is normal load followed by sliding speed and filler content. Further, a confirmation test is carried out to validate the result and it is seen that the grey relational grade is increased about 72.56% from the initial to the optimum condition. Finally, surface morphology is studied using scanning electron microscopy (SEM).

Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)

Keywords: ABS; $CaCO_3$; Grey taguchi; COF; Wear rate; Polymer composite

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1. Introduction

Nowadays, polymers and polymer based composites are used commonly in situations where a good tribological property is required. Homopolymers alone cannot satisfy the required properties for the tribological applications such as cams, brakes, bearings, gears etc., Thus to improve properties and to lower the cost of polymer products, fillers are employed. The fillers can be in micro and nano sizes of inorganic fillers, organic fillers and metallic particulate materials. The tribological behavior of polymers with the addition of fillers is of great interests in recent years to improve the friction coefficient and wear rate.

ABS (Acrylonitrile – butadiene – styrene) is a well-known engineering thermoplastic terpolymer over the past decades. Acrylonitrile gives chemical resistance and heat stability, butadiene gives toughness and impact strength and the styrene gives rigidity and easiness of processability. It has been used as a homopolymer or matrix of the composite materials. The tribological properties of ABS have been in studies over the years, whereas neat ABS has its limitations in tribology due to high friction coefficient and wear rate (Difallah et al., 2012). Hence, polymers containing inorganic fillers have been studied widely because of its growing industrial applications. Inorganic particulate fillers such as calcium carbonate, talc, mica, kaolin etc. of micrometer-sized particles are used to improve modulus, hardness and fracture toughness but at the cost of reduced impact strength and tensile strength in the polymer composites (Wang et al., 2008). Calcium carbonate is one of the most important fillers used in polymer composites. It has emerged as a promising reinforcer due to its easy mix and processing and also it may improve the mechanical, tribological and rheological properties of polymer composites (Lin et al., 2006). Calcium carbonate filled polymers are studied in many research articles related to the mechanical properties. Tang et al. (2002) and Liang (2005) studied tensile, impact and bending properties of $CaCO_3$ and hollow glass bead filled ABS and reported that for the injection molded specimens the tensile modulus increases with increasing ratio of fillers and tensile strength decreases gently with the increase of filler. Jiang et al. (2005) have studied micron-sized and nano-sized $CaCO_3$ with ABS and found that micron sized one is more effective than nano-sized $CaCO_3$. Many researchers have used inorganic fillers such as ZnO, TiO_2, and CuO and different polymers in the field of tribology to increase the properties (Yu et al., 2000; Zhang et al., 2009; Cho and Bahadur, 2005; Selvin et al., 2004).

Wang et al. (2012) have studied the mechanical and tribological properties of ABS filled with graphite and carbon black and found that the fillers can effectively decrease the COF and wear rate. Lin et al. (2006) have reported that the effect of $CaCO_3$ whiskers filled with polyether-ether-ketone (PEEK) has improved the tribological properties in dry sliding conditions. Youxi et al. (2007) have also revealed that $CaCO_3$ whisker and poly-tetra-fluoro-ethylene (PTFE) can improve wear resistance with PEEK polymer. Hence, researchers have used ABS material by incorporating various fillers in the field of tribology. But, there has been a little investigation on the development of ABS polymer with micron-sized $CaCO_3$ conventional filler. To obtain the best results in tribological properties, right amount of filler and operating conditions must be provided to get optimum responses.

The present study investigates the tribological behavior of ABS / $CaCO_3$ composites. The factors selected are % of filler (A), load (B) and speed (C) while coefficient of friction and specific wear rate are considered as the responses. To find out the optimum combination for multi-responses (coefficient of friction and wear rate), grey relational analysis coupled with Taguchi method is applied. Analysis of variance (ANOVA) is also used to find out the significant factors. An effort is made to study the morphology of wear tracks for the initial and optimum conditions after the tribological tests using SEM images.

2. Experimental details

2.1. Materials

Acrylonitrile-butadiene-styrene (ABS) is used as a matrix material in this study. It is Absolac – 920 of high flow medium impact grade with a density of 1.04 g / cm^3 and melt flow index of 21 g / 10 min. manufactured by Styrolution ABS Limited, India. The filler selected is Calcium carbonate ($CaCO_3$) supplied by Gulsan Polyol Ltd, India in the form of powder with a purity of 97%, mean particle size of 2 – 2.5 µm and bulk density of 2.71 g / cm^3.

2.2. Sample preparation

A Haake single screw extruder (Rheocord – 9000) with a screw diameter of 18mm and L/D ratio of 24:1 fitted with a rod die with a screw speed of 60 rpm and die temperature of 240°C is employed for the mixing of $CaCO_3$ powders into ABS pellets homogeneously. In order to improve mixing, powders of $CaCO_3$ and virgin ABS pellets are dried at 60°C in a vacuum oven for 6 hours to remove moisture. ABS with different compositions 5, 10 and 15 wt% of $CaCO_3$ fillers are extruded individually. The ABS / $CaCO_3$ with different compositions are pre-mixed manually in a zip-lock bag before extrusion. The temperature profile of the extruder is shown in Table 1 and the mixing for different compositions is carried out in a continuous manner. The extruded composites in the shape of rod are immediately cooled by water followed by air cooling. Then the composite rods are pelletized into granules form in uniform size by using a pelletizer machine. The pelletized composites are dried at 60°C in a vacuum oven for 6 hours to remove moisture before compression molding process. The pelletized granules are placed in a rectangular mold of size 150 X 100 X 8 mm^3 and subjected to hot compression mold (Carver Press, Germany) with a temperature of 260°C and load of 8 metric tonnes kept for 1 min and then lowered the load to 6 metric tonnes to allow the entrapped air out from the mold and kept for 15 min. Then, heat is turned off and the mold is allowed to cool in the compression machine itself at the room temperature for 2 hrs and kept at the same load prior to removing the composite rectangular bar. The specimens for tribological tests are cut from the rectangular bar with a specimen size of 20 X 20 X 8 mm^3.

Table 1 Temperature profile along the extruder barrel.

Feed Zone	Compression Zone	Metering Zone	Die
210°C	220°C	230°C	240°C

2.3. Design of experiments

The purpose of present study is to investigate the optimal parameter setting for the minimization of tribological properties namely coefficient of friction and specific wear rate of the composites. The tribological tests are carried out with different test conditions using three design parameters viz., filler content, load and speed each at three levels. The design parameters and their values are shown in Table 2 based on previous research studies (Tang et al., 2002; Liang, 2005; Jiang et al., 2005; Bahadur and Tabor, 1985; Biswas and Satapathy, 2009). The selection of design of experiments is based on orthogonal array on the basis of degrees of freedom of the experiment. An orthogonal array of L_{27} is used in this study considering both the main factor effects and the interactions. The L_{27} orthogonal array is chosen according to the total degrees of freedom (DOF) of the experiments. The main factor has 2 (no of levels minus 1, i.e., 3-1) degrees of freedom and for two way interaction of the factors, the degrees of freedom is 4. Therefore, total degrees of freedom will be (3 X 2) + (3 X 4) = 18. The total DOF of the orthogonal array (OA) should be greater than the experimental DOF of the factors. So, L_{27} OA having 26 DOF is chosen for the study. L_{27} has 27 rows corresponding to the number of experiments. Here, each row represents the test conditions and the column represents the test parameter. According to the linear graph shown in fig. 1, the first column is assigned to % of fillers (A), the second column is assigned to load (B) and the fifth column is assigned to the speed (C). The third and fourth column are assigned to the interaction of % of filler and load (A x B), sixth and seventh column assigned to the interaction of load and speed (A x C), eighth and eleventh column is assigned to the interaction of % of filler and speed (B x C) and the remaining columns are error terms (Glen, 1993). The complete table for L_{27} OA is omitted here for brevity. The tests are conducted as per the experimental design given in Table 3 at room temperature.

2.4. Friction and wear tests

Friction and wear tests of ABS / $CaCO_3$ polymer composites with different compositions are performed on a block on roller multi-tribotester TR25 (Ducom, India). It is used to measure the coefficient of friction of composites under dry non - lubricated condition. The composite samples 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. The surfaces of specimen and roller are cleaned with a soft paper before each test to ensure proper contact with the counter face. A loading lever is used to apply a normal load on the top of the specimen. The frictional force is measured by a force sensor. The frictional tests are carried out at three loads of 15 N, 25 N and 35 N and a three speed of 80 rpm, 100 rpm and 120 rpm with three % of filler i.e., 5, 10 and 15wt% respectively and performed all the tests with the time of 300 sec. The experimental data of coefficient of friction are recorded on a computer attached to the testing apparatus. The weight loss is used to calculate the specific wear rate. The samples are weighed before and after the experiments to an accuracy of 0.0001 g in a mettler toddler electronic balance. The specific wear rate (W_s) is calculated using equation (1) (Wang et al., 2012).

$$Ws = \frac{W_1 - W_2}{\rho * P * \upsilon * t} \tag{1}$$

where W_s is the specific wear rate in mm^3 / N.m, W_1 is the weight before the test in g, W_2 is the weight after the test in g, ρ is the computed density of composites in g / cm^3, P is the applied normal load in N, ν is the relative sliding velocity in m / s and t is the experimental time in sec.

Table 2 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

'*' initial testing conditions

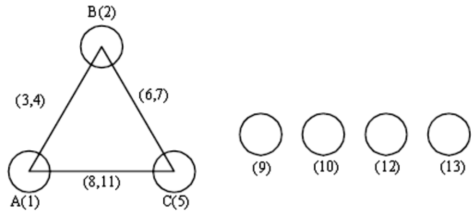

Fig. 1 Linear graph of L_{27} (3^{13}) orthogonal array

2.5. Grey relation analysis

The present study is focused on minimization of two responses of tribological properties namely coefficient of friction and specific wear rate of the composites. Grey relation analysis is used in this study, because it is an efficient tool for solving the inter-relationships among multi-responses (Deng, 1989). The first step in solving the grey relational analysis is to normalize the results of the experiments in the range between 0 and 1 based on the equation (2) which is lower-the-better criterion (Deng, 1990; 1992).

$$X_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{2}$$

where $x_i(k)$ is the normalized grey relational value for the k^{th} response , max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response, min $y_i(k)$is the smallest value of $y_i(k)$ for the k^{th} response, $y_i(k)$is the experimental value for the k^{th} response and i = 1 to 27, which is experiment number, k = 1 to 3 depends on the number of factors.

The second step is to find the grey relational coefficient of the responses from the normalized results which represent the correlation between the desired and actual experimental data according to the equation (3).

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{oi}(k) + \zeta\Delta_{\max}} \tag{3}$$

where $\xi_i(k)$ is the grey relational coefficient, Δ_{min} and Δ_{max} is the minimum and maximum values of absolute differences(Δ_{0i}) of all comparing sequences,$\Delta_{0i} = \parallel x_0(k) - x_i(k) \parallel$ is the difference of the absolute valuebetween $x_0(k)$ and $x_i(k)$, $x_0(k)$ is the reference sequence and ζ is the distinguishing coefficient $0 \leq \zeta \leq 1$. If equal weightage are given to the responses then ζ is 0.5 and it is widely accepted.

After calculating grey relational coefficients, the grey relational grade γ_i can be calculated by the equation (4). The higher values of grey relational grade are considered to be the best relation among the sequences and optimal level of each factor independently can be determined.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \tag{4}$$

where n is the number of responses.

By this way, multiple response problems are converted into a single response with the objective function of overall grey relational grade. The highest grey relational grade is considered to be the best relation among the sequences. Further, Taguchi method is used for the optimization of single grey relational grade performance characteristics (Taguchi, 1990; Ross, 1995). Taguchi has used loss function to measure the performance characteristic deviating from the desired value. Then, the value of loss function is transformed into signal-to-noise ratio to calculate the quality characteristics and evaluate the parameters. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). Usually, the standard S/N ratio has three categories of the performance characteristics, namely, smaller-the-better, nominal-the better and higher-the-better. The S/N ratio of grey relational grade is computed based on the three categories. The S/N ratio is calculated as the logarithmic transformation of the loss function by using larger-the-better criterion as per equation (5) as larger values of grey relational grade are required (Roy, 1990).

$$\frac{S}{N} ratio = -10 * \log_{10}(\frac{1}{n} * \frac{1}{y^2}) \tag{5}$$

where y represents experimental data for grey relational grade and n denotes the number of experiments.

2.6. Analysis of Variance (ANOVA) analysis

ANOVA is a statistical technique used to predict the significance of process parameters on the quality characteristics and also the percentage contributions of the factors and the interactions affecting the responses (Ozcelik and Sonat, 2009; Altan, 2010). The percentage calculations are calculated by the total sum of squared deviations from the total mean of grey relational grade. Using Minitab software (2001), ANOVA is performed to determine which parameters and interactions significantly affect the performance characteristics. In addition F-ratio (Fisher ratio) (Fisher, 1925) is used to determine which process parameter has the significant effect on the performance characteristics based on 95% confidence level.

3. RESULTS AND DISCUSSIONS

3.1. Grey relation analysis of COF and specific wear rate

In this study, the tribological tests are conducted to minimize the coefficient of friction and wear of polymer composites by optimizing the tribo testing parameters with the help of grey relation method. The experimental results of COF and specific wear rate are shown in Table 3. For this study, two responses are selected (COF and specific wear rate) and combined into a single response. The first step in grey relational analysis is to normalize the experimental results in the range between 0 and 1. It is done to avoid the problems of difference in units, scales and targets of the responses. The normalization of results is calculated according to lower-the-better criterion equation (2), where the minimum values of responses are the targets. The normalized values of both the responses are shown in Table 3. Ideally, the larger normalized values in both the responses are the best normalized value and are equal to unity. Next the grey relational coefficient is calculated from the normalized value according to equation (3). It is used to show the relationship between the ideal (best) and the actual experimental data. In the study equal weightage is given to the responses where the distinguishing coefficient ζ equal to 0.5 is used in the calculation. Table 3 shows the grey relational coefficient for COF and specific wear rate.

Table 3 Normalized and grey relational coefficient for responses.

Exp Run	1 (A)	2 (B)	3 (C)	Coefficient of friction	Specific wear rate (mm^3/Nm)	Normalized values (COF)	Normalized values (sp. Wear rate)	Grey coefficient (COF)	Grey coefficient (Sp. Wear rate)	Grey grade	S/N ratio (Grey grade)	Orders
1	1	1	1	0.2919	0.00210	0.3467	0.0637	0.4335	0.3481	0.3908	-8.1609	26
2	1	1	2	0.2270	0.00160	0.6326	0.3822	0.5764	0.4473	0.5119	-5.8163	18
3	1	1	3	0.2185	0.00170	0.6700	0.3185	0.6024	0.4232	0.5128	-5.8010	17
4	1	2	1	0.2372	0.00150	0.5877	0.4459	0.5480	0.4743	0.5112	-5.8282	19
5	1	2	2	0.2697	0.00130	0.4445	0.5732	0.4737	0.5395	0.5066	-5.9067	20
6	1	2	3	0.1695	0.00090	0.8859	0.8280	0.8142	0.7441	0.7791	-2.1681	4
7	1	3	1	0.1886	0.00110	0.8018	0.7006	0.7161	0.6255	0.6708	-3.4681	7
8	1	3	2	0.2157	0.00100	0.6824	0.7643	0.6115	0.6797	0.6456	-3.8007	9
9	1	3	3	0.1436	0.00070	1.0000	0.9554	1.0000	0.9181	0.9591	-0.3627	1
10	2	1	1	0.2279	0.00220	0.6286	0.0000	0.5738	0.3333	0.4536	-6.8665	23
11	2	1	2	0.2013	0.00180	0.7458	0.2548	0.6630	0.4015	0.5323	-5.4769	14
12	2	1	3	0.2724	0.00120	0.4326	0.6369	0.4684	0.5793	0.5239	-5.6150	15
13	2	2	1	0.3706	0.00150	0.0000	0.4459	0.3333	0.4743	0.4038	-7.8767	25
14	2	2	2	0.2285	0.00130	0.6260	0.5732	0.5721	0.5395	0.5558	-5.1016	13
15	2	2	3	0.2780	0.00120	0.4079	0.6369	0.4578	0.5793	0.5186	-5.7033	16
16	2	3	1	0.2262	0.00100	0.6361	0.7643	0.5788	0.6797	0.6292	-4.0242	12
17	2	3	2	0.1725	0.00073	0.8727	0.9363	0.7971	0.8870	0.8420	-1.4938	3
18	2	3	3	0.2207	0.00090	0.6604	0.8280	0.5955	0.7441	0.6698	-3.4811	8
19	3	1	1	0.3485	0.00181	0.0974	0.2484	0.3565	0.3995	0.3780	-8.4502	27
20	3	1	2	0.2678	0.00165	0.4529	0.3503	0.4775	0.4349	0.4562	-6.8169	22
21	3	1	3	0.3100	0.00148	0.2670	0.4586	0.4055	0.4801	0.4428	-7.0758	24
22	3	2	1	0.2068	0.00109	0.7216	0.7070	0.6423	0.6305	0.6364	-3.9254	11
23	3	2	2	0.2638	0.00139	0.4705	0.5159	0.4857	0.5081	0.4969	-6.0746	21
24	3	2	3	0.2515	0.00086	0.5247	0.8535	0.5126	0.7734	0.6430	-3.8358	10
25	3	3	1	0.2107	0.00088	0.7044	0.8408	0.6285	0.7585	0.6935	-3.1791	6
26	3	3	2	0.1854	0.00085	0.8159	0.8599	0.7308	0.7811	0.7560	-2.4296	5
27	3	3	3	0.1902	0.00063	0.7947	1.0000	0.7089	1.0000	0.8545	-1.3658	2

Next, the grey relational grade can be calculated by averaging the grey relational coefficients corresponding to each performance characteristics according to equation (4). The grey relational grade is used to show the relationship among the responses. By using this grade, the multi-response characteristics could be solved. The grey relational grade and their orders are shown in Table 3. The overall mean of grey relational grade is found to be 0.5916. According to grey relational analysis, the optimum level of the factors will be the level with the highest grey relational grade. Hence, from Table 3, experiment number 9 shows the highest grade value, which means the best multi-response characteristics are obtained with the combination of A1B3C3 (5 wt% filler content, 35N load and 120rpm) followed by A3B3C3.

The optimal parameters obtained from the grey relational grade at different levels can be independent because design of experiments is orthogonal. Hence, Taguchi method is used to find the mean for each factor of each level. Using Minitab 16 statistical software, specially designed for design of experiments application, the experimental data for grey relational grade are converted into S/N ratio according to larger-the-better criterion as per equation (5) where larger values of grey grade are required and are shown in Table 3. This study employs a response table to calculate the mean and S/N ratio average grey relational grade for each factor levels and are shown in Table 4 and Table 5. For predicting the measure of performance of factors, the possible interactions between the factors are considered, before analysing the experimental data using the software. Thus, to find out the presence of interaction effects, design of experiments incorporates a simple means of testing. The highest average grey relational grade for each factor will be the optimum parameters for this study. The optimum levels of process parameter based on the response grey relational grade are A1B3C3 for the factors A, B and C. The influences of factors with their levels are shown in fig. 2. In the main effects plots the point near the average horizontal line has less significant effect and the one which has highest inclination will have most significant effect on the responses. It is clear from fig. 2 that for factor A, the highest point is at level 1 but it is near to the average horizontal line and it has less significant effect on the responses, highest point for factor B is at level 3 and as the highest inclination which has most significant effect on the responses and for factor C is at level 3 and it as significant effect next to factor B. It is clear from fig. 2, that while increasing the load and speed the grey relational grade will be increased. Table 4 & 5 also show the delta value which is the difference between the maximum and minimum of average grey relational grade of each factor. It is clear from the analysis that factor B has the highest delta value and it has the most significant effect on the responses followed by factor C and factor A. The results are in well agreement with the previous studies (Cho et al., 2005; Wang et al., 2012; Rashmi et al., 2011; Chang et al., 2013).

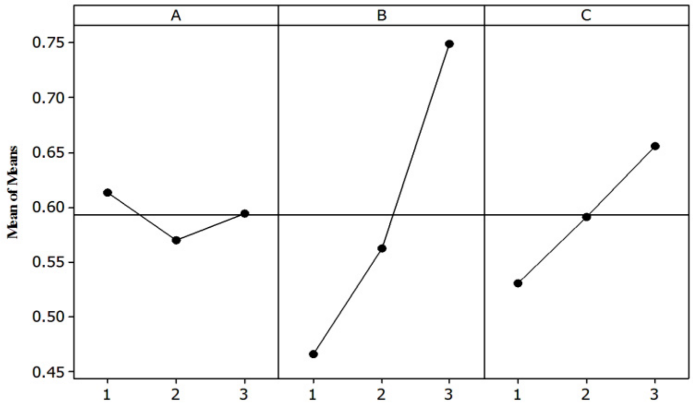

Fig. 2 Influences of factors with their levels

Table 4 Response table for each factor levels of S/N ratio

Average S/N ratio for each factor level (Grey relational grade)			
Level	A	B	C
1	-4.590*	-6.676	-5.753
2	-5.071	-5.158	-4.769
3	-4.795	-2.623*	-3.934*
Delta	0.481	4.053	1.819
Rank	3	1	2

'*' indicates optimal process level

Table 5 Response table for each factor levels of mean

Average mean for each factor level (Grey relational grade)			
Level	A	B	C
1	0.6098*	0.4669	0.5297
2	0.5699	0.5613	0.5893
3	0.5953	0.7467*	0.6560*
Delta	0.0399	0.2798	0.1263
Rank	3	1	2

'*' indicates optimal process level

3.2 ANOVA

The ANOVA table for the grey relational grade of % of filler, Load and speed are calculated by using Minitab software and performed according to 95% level of confidence and are shown in Table 6. F – Ratio is calculated and it shows that factor B and C have the most significant effect on the response. The percentage contribution of each factor and their interaction are also shown in ANOVA table. Factor B has the percentage contribution of 61.67% and it is the most significant factor which affects the quality characteristics followed by factor C as 12.14% and factor A as 1.24%. In the case of interactions, A x C interaction has the effect on the responses followed by A x B and B x C. The results of ANOVA analysis are supported by previous studies (Cho et al., 2005).

Table 6 ANOVA table for each factor

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F - ratio	% contribution
A	2	0.007334	0.003667	0.75	1.240010
B	2	0.364729	0.182365	37.3*	61.66723
C	2	0.071807	0.035904	7.34*	12.14090

AxB	4	0.028055	0.007014	1.43	4.743451
AxC	4	0.063229	0.015807	3.23	10.69056
BxC	4	0.017183	0.004296	0.88	2.905248
Error	8	0.03911	0.004889		6.612596
Total	26	0.591447			100

Significant at 95% confidence level ($F_{0.05,2,8} = 4.46$ & $F_{0.05,4,8} = 3.84$)
"*" indicates most significant factor.

3.3 Confirmation test

The confirmation tests are carried out based on the response of grey relational grade which shows that the optimal parameter combination is A1B3C3 and to validate the experimental results. Using the optimal level of testing parameters, the estimated grey relational grade, $\bar{\gamma}$ is calculated according to equation (6) (Roy, 1990), and the factors which are insignificant are neglected while calculating the grade.

$$\bar{\gamma} = \gamma_m + \sum_{i=1}^{0} (\bar{\gamma}_i - \gamma_m) \tag{6}$$

where γ_m is the total mean grey relational grade, $\bar{\gamma}_i$is the mean grey relational grade at the optimal testing parameter level and 0 is the number of main design process parameters that significantly affect the wear performance of polymer composites. The comparisons of the estimated and the actual grey relational grade are shown in Table 7. It is found from the study that the optimal parameter combination enhances the grey relational grade from 0.5558 to 0.9591 by 72.56%. Hence, the tribological properties are improved by using grey relational analysis.

Table 7 Confirmation test for estimated and actual grey relational grade

	Initial parameter	Predicated Optimal	Experimental
Level	A2B2C2	A1B3C3	A1B3C3
COF	0.22850		0.14360
Specific wear rate	0.00130		0.00070
Grey relational grade	0.55580	0.82930	0.95910

3.4 Scanning electron microscopy (SEM) analysis

SEM images are used to know the effect of $CaCO_3$ filler on the wear resistance of the composite. SEM examinations are carried out for the composite surfaces coated with platinum on a JEOL (model JSM 6390LV, Japan) microscope to observe the morphology of wear tracks. Fig. 3 (a) shows the image of initial condition used for this study of 10 wt% filler content, 25N load and 100rpm speed. Fig. 3 (b) shows for optimal condition from the grey relation and ANOVA analysis of 5 wt% filler content, 35N load and 120 rpm speed. From the micrographs, it is observed that worn surfaces are mainly composed of longitudinal groove that is caused by micro-cutting and micro-ploughing sliding action. At increased load and speed, the friction coefficient and wear rate decreases. This is because, the surface temperature of the composites increases with the high load and speed, hence the composite surfaces become soft caused by frictional heat at the interface, thus the reduction in response occurs (Chang et al., 2013). From the micrographs of fig. 3 (b), it is clear that that the composite surface is smooth due to frictional heat generated and small amount of debris are formed with increased load and speed. Hence COF and wear rate decreases, which supports the optimal condition from the analysis.

4. Conclusions

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 rate 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, load and speed. Optimization of friction and wear rate test parameters are done with the help of grey Taguchi design of experiments. From the combination of analysis, both the responses are combined into a single response of grey relational grade. It can be found that the 5% of filler content, 35 N of load and 120 rpm of speed (A1B3C3) gives the optimum values of grey relational grade for ABS / $CaCO_3$composites. The confirmation test shows the improvement of grey relational grade from initial to optimal condition by 72.56%. The factor, load (B) affects the grey relational grade significantly followed by speed (C) and % filler (A). It can be concluded from this study that with the addition of micron-sized $CaCO_3$ at the right combination of design parameters, the tribological properties get improved.

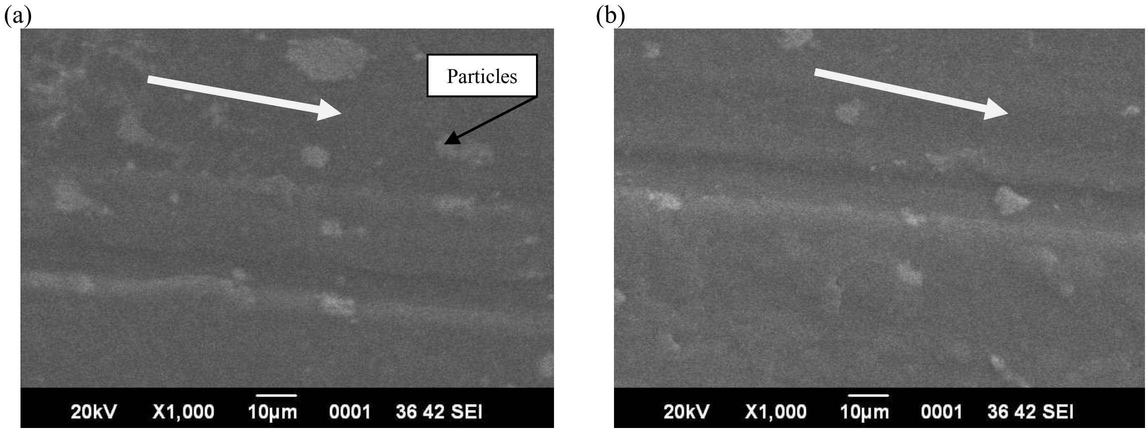

Fig. 3 (a) initial condition (A2B2C2) (b) optimal condition (A1B3C3)

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