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WEAR PERFORMANCE ANALYSIS OF NYLON-6/BORON NITRIDE POLYMER COMPOSITES USING TAGUCHI-PARETO AND TAGUCHI-ABC METHODS

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ABSTRACT

Despite the industrial popularity of nylon 6 composites, their wear performance portrays a substantial knowledge gap on parametric importance. Consequently, this study optimizes and prioritizes the wear performance parameters of nylon 6/boron nitride composites using the Taguchi-Pareto and Taguchi-ABC methods based on 80-20 Pareto rule and the ABC analysis, using signal-to-noise ratios. From the literature information, the principal parameters considered are the %wt of reinforcement, normal load, sliding speed, and sliding distance, respectively. The results showed that the optimal parametric setting using the Taguchi-Pareto method is 4wt % of boron nitride Nanocomposite, 15 N of normal load, 100 rpm of sliding speed and 500m of sliding distance. The limitation of this study is the difficulty in deducing the most significant delta values or ranks through the parameters. This work drive towards more practically focused wear performance studies by industrial practitioners, showing critical optimization and prioritization procedures in a single study.

KEYWORDS

Nylon 6, boron nitride, composites, optimization, prioritization

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1. INTRODUCTION

Nylon 6 is one of the most important engineering materials as it has wide applications in gears (Imrek, 2009; Senthilvelan and Gnanamoorthy, 2009; Kumar et al., 2021a,b), wears ships and chain guards, seals, circuit insulation boards and machine guards, among others (Rajesh et al., 2021). When strengthened with boron nitride, the polymer composites developed from such an association have wider utility than as previously mentioned in industrial applications (Kumar and Reddy, 2020). However, in wear performance improvement efforts which are central to the quality of service provided by materials made up of nylon-6/boron nitride polymer composite, a substantial knowledge gap exists, which is illustrated here regarding resource allocation to parameters during the wear performance analysis (Haidear et al., 2017; Kumar et al., 2021b).

At present, the conventional approach to resource allocation for wear performance analysis is divided into steps. At first, the wear performance analysis project is segregated into tasks, and the resources are assigned (Haidear et al., 2017). Then the resource characteristics are established, which is followed by resource levelling. Then resources are reallocated if essential, and utilization is monitored. This procedure is human-centered and wasteful, requiring skilled personnel, experience and time for proper and efficient execution. Unfortunately, for a new fabrication process where composite development information is sparse or unavailable, a successful resource allocation may not be guaranteed as experienced and skilled workers may not always be available. Therefore, alternative approaches are required to achieve an effective resource allocation for the wear performance analysis problem.

Furthermore, in the development and fabrication of the nylon6/boron nitride polymer composites, the system parameters, when optimized, are often not distinguishable from one another when the Taguchi-experimental design optimization approach is deployed. This is because there is a lack of prioritization mechanisms in the parametric evaluation. But assigning the same degree of importance to all the wear performance analysis parameters is a huge error as resources are shared for wear analysis equally without due consideration for requirements. The application of the Taguchi method to the wear performance analysis problem, such as in Kumar and Reddy (2020), is inadequate to amount to such needs in the experimental data, see also (Kumar et al., 2022). To overcome this problem, a combined Taguchi method and Pareto method known as the Taguchi-Pareto approach has been proposed as one of the methods to optimize and priorities the wear operations parameters. Moreover, the combination of the Taguchi method and ABC classification scheme, known as the Taguchi-ABC method, is another proposed method to solve the concurrent optimization and prioritization problem.

However, some articles have proved that the traditional Taguchi method in optimizing process parameters may cause erroneous decision-making regarding which parameter the resources for the fabrication and testing process should be allocated to. Therefore, the Taguchi method has been combined with other methods for enhancement in outputs and decision-making. To the best of the present author's knowledge, past authors have avoided tackling the resource distribution aspect of the wear performance analysis while attempting to optimize parameters using the Taguchi method for the nylon 6 and/or boron nitride composites in industrial applications. But prioritization is an important part of establishing an unbiased resource distribution to parameters while fabricating composites in industrial applications. This gap makes the Taguchi methodical improvement a worthwhile goal and fertile ground to apply the Pareto scheme as the Taguchi-Pareto method and the ABC classification scheme as the Taguchi-ABC method in the process of nylin-6/boron nitride composites and overcoming the weakness of erroneous resource allocation and waste.

Research on optimization processes of nylon-6/boron nitride composites has been active for some years now. Boopathy et al. (2022) analyzed the mechanical characteristics of nylon 6/SiC and nylon6/B4C composites by focusing on the injection moulding pressure, and wt% reinforced material composition as the influential parameters. The key conclusion is that at the injection pressure of 80MPa and considering the 5%SiC superior tensile strength, while at the 90MPa of injection pressure and considering the 5%B4C, better impact strength was achieved. The drawback of their article is the few parameters considered in the analysis. Vasanthkumar et al. (2022) employed the friction wear principle to nylon6 fortified seashell particles to analyze the wear of nylon 6 composites, and the key responses analyzed are the interface temperature, material loss because of wear and frictional coefficient. It was concluded that the interface temperature depended mostly on rotational speed (41.61%). Furthermore, material loss because of wear was substantially affected by fortification by the seashell particles (35.71%), while rotational speed mostly influenced the frictional coefficient (i.e. 41.48%) and reinforced with seashell particles (18.18%w/w) less significantly influenced the frictional coefficient. The article reported success in implementing response surface methodology and grey wolf optimizer. The drawback of the grey wolf optimizer is the poor local searching attributes.

Cabello-Alvarado et al. (2022) extruded and analyzed nylon6/clinoptilolite composites using ultrasound-aided means. Chemical analysis in four ranges, notably differential scanning calorimetry, Fourier transform infrared spectroscopy, scanning electron microscopy, and thermogravimetric analysis was conducted on the composite. It was declared that clinoptilolite, being homogeneously distributed within the matrix of the composite, disallowed the development of stress intensity points. The drawback of the study is the limited attention to the parameters that could bring about changes in the mentioned and analyzed chemical contents. Randhawa and Patel (2020) developed nylon 6 and nylon6/h-BN composites under mechanical and tribological investigation schemes. The tensile strength, modulus of elasticity, hardness and impact strength are the principal parameters identified in work, while the wear rate and coefficient of friction are the responses of the system. It was reported that the modulus of elasticity increased by 64.5% while the tensile strength grew in performance by 15.2%. The growth in the performance of impact strength and hardness is 6% and 3.45%, respectively. By considering the wear rate and coefficient of friction of the composites, there is a decrease of roughly 4wt% filler reinforcement because of the smooth transition film development. At diverse test situations, growth in the coefficient of friction and wear resistance were established at 10-15% and 8-10%, correspondingly. However, the drawback of the article is the omission of some important optimization tools from work.

Furthermore, in this article, optimization approaches are proposed to determine the optimal parameters of the wear process while considering nylon b/boron nitride composites. The work shows that decisions could be made based on the parametric values of the parameters considered and their ranks. Our approach is unique since it combines optimization with the prioritization of parameters for possible parametric resource distribution intentions. This is an idea that shows what preference should be given to certain parameters above others and decision-makers did not know about this before. Thus, the main contributions of this paper are as follows:

(1) Three methods, namely Taguchi, Taguchi-Pareto and Taguchi-ABC utilize factor-level, orthogonal array and signal-to-noise information to extract optimal parametric values for the wear process of nylon 6/boron nitride composites.

(2) Established ranks for parameters that can serve as a strong motivation for resource distribution decisions and causes effectiveness even during sparse resource availability.

(3) The Taguchi-Pareto and Taguchi-ABC methods outputs prioritized the order of parametric choices and optimal values of parameters.

Aside from the mentioned contributions, the novelty of this article is the unique presentation of methods that can transform limited information on wear parameters into a useful signal and noise framework that classifies parameters according to some important details.

2. METHODS

2.1. Why the choice of parameters?

The research aims to develop a framework to optimize the parameters of the wear process considering nylon 6/boron nitride composites. This is based on the challenge faced by process engineers partly resulting in efficient operations and sustainability problems. This, motivation for the choice of the parameters is given. Moreover, given that the research presented in this work aims to optimize the parameters of the wear process, these parameters were chosen by the contribution that they make to the optimization of the wear process. Firstly, all the analysed parameters are intended to examine the degree to which the system can fall out of sub-optimal measures. The sliding distance was chosen because it declares an intension to declare how much declares an intention to declare how much travel the nylon 6/boron nitride composite has made. It is based on the assumption that greater distance travelled by the composite leads to greater removal of the surface material of the composite due to wear. In addition, it is an indicator of a significant source of parameters for the wear performance evaluation.

The normal load was chosen because a high normal load directly stimulates more particle rupture for the nylon 6/boron nitride composite generating more debris. This % weight of reinforcements is based on the understanding that reduced wear rate is triggered during the rubbing action of the surfaces of the composite because of the clustering of the reinforcements, which leads to harder particles within the nylon 6/boron nitride composites. Given that this parameter is especially prominent in wear analysis, it is considered in the context of optimization of the composite considered in the current examination. The sliding speed was chosen because a growing relationship exists in the wear volume of composites as one considers the growth of the normal load and speed. This motivation is a substantial aspect of the present study since the article examines the optimization of parameters to establish the gap in values between optimal and sub-optimal thresholds. The outcomes of such evaluations of a parameter may lead the way in the abandonment of intuition and embarrassing optimization for improved wear process evaluation.

From the above discussion, it is understood that the mentioned parameters of sliding distance, sliding speed, percentage weight of reinforcement and normal load are very critical parameters of the wear process. It should be efficient to prevent system degradation for an extended lifespan of the nylon 6/boron nitride composites. Thus, optimization is needed for the wear process while trial and error should be eliminated to avoid sub-optimal threshold of wear parameters.

2.2. Procedure for the computation of the Taguchi-Pareto method

Step 1: Collect experimental data of the composite by parametric classification and group them into levels.

Step 2: Define the orthogonal levels to use by taking note of the factor-level combination.

Step 3: Transform the orthogonal levels to use by taking note of the factor-level table guidance.

Step 4: Compute the signal-to-noise ratios according to one or more of the signal-to-noise criteria, Equations (1) to (3) (Ikedue and Oke, 2023).

Smaller-the-better criterion:
$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^2 \tag{1}$$

Nominal-the-best criterion:
$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} \frac{\mu^2}{\sigma^2} \tag{2}$$

Higher-the-better criterion:
$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2} \tag{3}$$

Where n denotes the counts of experimental trials for the ith set, σ indicates the standard deviation, μ stands for the mean, yi is the value of the parameter of interest η and represents the signal-to-noise notation.

Step 5: Identify the signal-to-noise ratios falling into the Pareto scheme

Step 6: Develop the average signal-to-noise ratios

Step 7: Compute the delta values, associate ranks of the parameters and determine the optimal parametric settings

2.3 Procedure for the calculation of the Taguchi-ABC method

Step 1: Follow steps 1 to 4 of section 3.1

Step 2: Establish the signal-to-noise ratios according to the ABC classification scheme

Step 3: Follow steps 6 and 7 of section 3.1.

3. RESULTS AND DISCUSSION

The subjects of presentation in this section are the Taguchi-Pareto and Taguchi-ABC methods. First, the Taguchi method, as presented by Kumar and Reddy (2020), is used, and Pareto and

ABC concepts are added to make the new methods of Taguchi-Pareto and Taguchi-ABC. Initially, Kumar and Reddy (2020) utilized the L9 orthogonal array, defined the configuration and then diverted to ANOVA catenations. However, more importantly, the present authors navigate to the Pareto analysis and the ABC classification scheme after obtaining the Taguchi results, which are only obtainable after the computations of the signal-to-noise rations, averages of the ratios, delta value estimation and the optimal parametric setting development. From Table 1, the columns indicate the experimental trial number parametric symbols of N, W, NL, SS, and SD, representing the weight percentage, normal load, sliding speed and sliding distance, respectively. After the trial number, the next set of four columns is the orthogonal matrix, while the next four columns are the translated orthogonal arrays. The column following is the total for the signal-to-noise ratios. In Table 1, considering the first row after the heading, the value 1 represents the count, and there are 9 counts in all running through 9 rows.

Table 1. Factor-level analysis in an original orthogonal array and translated forms and the signal-to-noise ratios, (Kumar and Reddy, 2020).

	Orthogonal arrays for Factors				Translated orthogonal Arrays				Smaller the better SNR Criterion	
Exp. trial	W	NL	SS	SD	W	NL	SS	SD	SNR = $-10\log\frac{1}{n}\sum_{i=1}^{n}y_i^2$	Cumulative SNR criterion (%)
1	1	1	1	1	4	10	100	500	-48.1311	10.3720
2	1	2	2	2	4	15	200	750	-51.7807	21.5305
3	1	3	3	3	4	20	300	1000	-54.3553	33.2438
4	2	1	2	3	12	10	200	1000	-54.1508	44.9131
5	2	2	3	1	12	15	300	500	-49.2989	55.5368
6	2	3	1	2	12	20	100	750	-51.5613	66.6480
7	3	1	3	2	20	10	300	750	-52.1285	77.8814
8	3	2	1	3	20	15	100	1000	-54.0253	89.5236
9	3	3	2	1	20	20	200	500	-48.6153	100
								Total	-464.0470	

Key: BN, %wt (W), Normal load, N (NL), Sliding speed, rpm (SS) and Sliding distance, m (SD)

The next four columns after the experimental trial contain the orthogonal arrays with a minimum value of 1, indicating the representation of the first level, 2 for the second level, 3 for the third level and the fourth level. If we consider the second column labelled as W, under it, levels 1, 2 and 3 are represented every three times. This appears to be of a similar pattern with the level representation under labels NL, SS and SD. For the next column, W, under the translated scheme, under trials 1 and 4 is shown. This is read from Table 1, presented by Kumar and Reddy (2020), which is the intersection of factor BN, used as W in the present case and level 1. Along the column of W under the translated scheme, the next two entries are still 4 and 4, which are the interpreted values of level. So, the interpretation is made likewise, and Table 1 is partially completed.

To illustrate how the signal-to-noise ratios were evaluated, the choice of the criterion among smaller the better, larger the better and nominal the best needs to be made first. Considering the normal load, for instance, work materials that experience a higher normal load during the wear process are more likely to wear fast, which is undesirable. Therefore for the normal criterion load, the smaller, the better criterion is desirable and chosen. Next, we consider the criterion is sliding speeds. It is known that high sliding speeds could increase the interface temperature while frictional contact between the nylon6/boron nitride composite and the wear machine is considered. But high temperature degrades the material quality is undesirable in this situation. Therefore, the smaller, the better criterion is desired for the sliding speed parameter. On the sliding distance, the literature ascertains that the wear rate for elevated draw ratios decreases with the sliding distance, promoting the use of smaller shading distances if lower wear rate of the nylon6/boron nitride composite. Therefore, while selecting a criterion of the signal-to-noise ratio for the sliding distance, the smaller better criterion is desired. Concerning the % weight of reinforcement, experts argue that smaller diameter rebar that is distributed all through the composite material cause more effective distribution of local and wear attack on the material instead of concentrating the smaller % weight of reinforcement for the nylon6/boron nitride composite, the smaller, the better criterion is desired.

Now, it is observed that for all the four parameters of interest in this article, namely normal load, sliding speed, sliding distance and % weight of reinforcement of composite, it is justifiable to choose the smaller, the better criterion, then Equation (1) is used in the analysis of the parameters.

From this stage, the computation of the signal-to-noise ratio is made by illustrating experimental trial 1. Along the first row representing experimental trial 1, the translated values of the orthogonal arrays for W, NL, SS and SD into values of 4, 10, 100 and 500 are noted. Here Equation (1) is applied with the values of 4, 10, 100 and 500 being yi at each instance. By complying with the application of Equation (1), yi2 may first be calculated as 16, 100, 10000 and 250,000, respectively. When n is 4, which is the number of parameters, then the value of the reciprocal of n that is desired is 0.25. By applying the logarithm as appropriate, the S/N ratio obtained for experimental trial 1 is -48.1311. Then, for experimental trials 2 to 9, the values obtained are -51.7807, -54.3553, -54.1508, -49.2989, -51.5613, -52.1285, -54.0253 and -48.6153, respectively.

3.1. Taguchi-Pareto method

As opposed to the conventional approach of evaluating the Taguchi method, where we proceed to the development of the averages for the signal-to-noise ratios, from the signal-to-noise ratios, percentage representations are made, and truncation of experimental trials to choose those qualified for the Pareto scheme is made. The percentage signal-to-noise ratios are evaluated for each experimental trial, with the least being 10.3720 for experimental trial 1 and the highest being 11.7133 for experimental trial 3. Then, cumulative of the percentage signal-to-noise ratios are made where the first value for the experimental trial is 10.3720, and the last value is 100% for experimental trial 9. Now, by applying the 80-20 Pareto rule, the cut-off for the more important experimental trials is 80%, of which 77.8815% (experimental trial 7) is closer to it than 89.5237% (experimental trial 8). Therefore, the cut-off is 77.8814%, which is experimental trial 7. It means that further analysis of computing the average signal-to-noise ratio should be restricted to only experimental trials 1 to 7, and experimental trials 8 and 9 are eliminated from the calculations.

To obtain the average signal-to-noise ratios, a table is set up with levels along the rows and parameters along the columns and the averages of the signal-to-noise ratios for each parameter according to the levels included in the table. Consider the parameter W, and it can occur at three levels, 1, 2, and 3. Now, computing the average response value for parameter W at level 1, we need to check the orthogonal array to understand which of the experimental trials from 1 to 7 has level 1 attached to it. From this, the average may be computed in Table 2.

Ongoing through the orthogonal array, it was found that experimental trials 1, 2 and 3 are concerned. Thus, an average of the corresponding signal-to-noise ratios of -48.1311, -57,7807 and -54.3553 is made as -51.4224 for level 2 of parameter W, and the average is obtained from the signal-to-noise ratios of experimental trials 4, 5 and 6 to obtain -54.1508, -49.2989 and -51.5613, respectively. Then the average is obtained as -51.6703. Accordingly, for level 3 of W, only the value of the signal-to-noise ratio of experimental trial 7 is available. Hence the average is -52.1285. Similarly, the orthogonal array is read, and the averages of the signal-to-noise ratios are computed for all other parameters of NL, SS and SD. At variance from the conventional Taguchi method, the averages for the response table are computed to exclude the signal-to-noise values of experimental trials 8 and 9. By following this idea, the response table is completed. It is from the response table that the values are -51.4224, -50.5398, -49.8462 and -48.715 for W, NL, SS and SD, respectively. These points determine the optimal parametric as 4wt% of boron nitride nanoparticles, 10N of normal load, and 100rpm of sliding distance.

Table 2. Response table for Taguchi-Pareto scheme

	Factors			
Level	W	NL	SS	SD
Level 1	-51.4224	-51.4701	-49.8462	-48.715
Level 2	-51.6703	-50.5398	-52.9657	-51.8235
Level 3	-52.1285	-52.9583	-51.9276	-54.253
Delta	0.7062	2.4185	3.1196	5.5381
Ranking	4th	3^{rd}	2nd	1^{st}

Note: Optimal parametric settings: $W_1NL_2SS_1SD_1$

In Kumar and Reddy (2020), the optimal parametric setting was not determined, but the present authors calculated the same and compared results with those obtained in the present article. The optimal parametric settings given by the Taguchi method are W, NL, SS, and SD, which is interpreted as 4 wt% of boron nitride nanoparticles, 10 N of normal load, 100 rpm of sliding speed and 500m of sliding distance. From the Taguchi-Pareto method, the delta values are 0.7062, 2.4185, 3.1196 and 5.5381, which are for the parameters W, NL, SS and SD, respectively. The ranks for the parameters are then sliding distance as the first (most important parameter), sliding speed as the second, normal load as the third and % weight of the boron nitride nanoparticle reinforcement in the composite as the 4th position (the worst in importance). From the Taguchi method, the obtained delta values are 0.2479, 0.2315, 0.6884 and 5.4954 for the parameters W, NL, SS and SD, respectively. The radius for the parameters is then the sliding distance as the first and most important parameter, the sliding speed as the second, the % weight of the boron nitride nanoparticle reinforcement in the composite as the third position and normal load as the fourth position. There are concurrent results from the ranking of sliding distance and sliding speed as first and second, respectively, in both the Taguchi-Pareto and Taguchi methods. However, the differences are the rating of the % weight of reinforcement and normal load, which are given as 3rd and 4th in the Taguchi method, respectively but 4th and 3rd, respectively, in the Taguchi-Pareto method.

3.2. Taguchi-ABC method

The Taguchi-ABC method is an extension of the Taguchi method whereby the percent-signal-to-noise ratios are analyzed according to the A, B and C components of the ABC classification scheme. Part A of the ABC classification scheme states that roughly 79% of the percentage signal-to-noise ratios should be cut off as the real value, and then the response table is developed based on this cut-off value. Parts B and C allocate 69% and 59%, respectively, of the percentage signal-to-noise ratios and subsequent evaluations, which are made in the response table until the optimal parametric settings, ranks and delta values are evaluated.

Now, part A of the Taguchi-ABC method is analyzed from the cumulative percentage signal-to-noise ratios. Here, there are two values to consider regarding the 79% cut-off point, which are 77% and 89%. However, 77% require only roughly two counts before achieving a 79% cut-off, whereas 89% require roughly ten counts before attaining the 79% cut-off. Since 77% is chaser to 79% cut off than 89%, it is chosen as the cut off at experimental trial 7 while experimental trials 8 and 9 are excluded from the analysis. Interestingly, the same analysis conducted for the Taguchi-Pareto coincidentally applies to the Part A of the Taguchi-ABC scheme and may not be repeated for brevity reasons. Also, the computational details of the Taguchi-Pareto and Taguchi methods applied earlier are extended to the Part A of the Taguchi-ABC method, Table 3.

Table 3. Response table for Part A of the Taguchi-ABC scheme.

	Factors			
Level	W	NL	SS	SD
Level 1	-51.4224	-51.4701	-49.8462	-48.7150
Level 2	-51.6703	-50.5398	-52.9657	-51.8235
Level 3	-52.1285	-52.9583	-51.9276	-54.2530
Delta	0.7062	2.4185	3.1196	5.5381
Ranking	4th	3rd	2nd	1st

Note: Optimal parametric settings: $W_1NL_2SS_1SD_1$

Furthermore, Part B of the Taguchi-ABC method requires a 69% cut-off. Now, as the cumulative percentage as options to Part B of the Taguchi-ABC methods are 66.65% at experimental trial 6 and 76.88% at experimental trial 7, the cut-off point for 69% for the Part B of the Taguchi-ABC method is chosen to 66.65% at experimental trial 6. The implication is that the average signal-to-noise ratios will be computed based on only six experimental trials. For this aspect of the Taguchi-ABC method, the response table is shown in Table 4.

Table 4. Response table for Part B of the Taguchi-ABC scheme.

	Factors			
Level	W	NL	SS	SD
Level 1	-51.4224	-51.1409	-49.8462	-48.7150
Level 2	-51.6703	-50.5398	-52.9657	-51.6710
Level 3	0	-52.9583	-51.8271	-54.2530
Delta	0.2480	2.4185	3.1196	5.5381
Ranking	4th	3rd	2nd	1st

Note: Optimal parametric settings: $W_1NL_2SS_1SD_1$

To calculate the individual cells, the procedure is implemented as follows. For the intersection of levels 1 and W, all the experimental trials 1, 2 and 3 are involved, and the averages of the signal-to-noise ratios, of -48.1311, -51.7807 and -54.3553, resulting in -51.4224. This value is placed at the intersection of levels 1 and W. At the intersection of levels 2 and W, experimental trials 4, 5 and 6 are concerned with values of -54.1508, -49.2989 and -51.5613, yielding an average of -51.6703. Furthermore, the value at the intersection of levels 3 and W is the average of experimental trial 7 is already cut off for the Part B of the Taguchi-ABC method. This means that zero is allocated to the cell being considered.

To compute the values for levels 1,2, and 3 of NL, the averages of the equivalent cells are taken as usual. By starting with the computation of the cell containing the intersection of NL and level 1, only two values of the SNR, namely -48.1311 and -54.1508, are involved. The average is -51.1409. For the cell of the intersection of NL and level 2, the average of -51.7807 and -49.2989 is obtained as 50.5398. Furthermore, the intersection of NL and level 3 yields an average of -52.9583. As we move to the parameter SS, to obtain the intersection of the SS in level 1, the average of -48.131 and 51.5613 is sought to yield -49.8462. For the intersection of SS and level 2, the average of -51.7807 and -54.1508 is obtained as -52.9657. For the intersection of SS and level 3, -54.352 and -49.2989 are concerned, and the average is -51.8271. For the SD parameter, the average of -48.1311 and -49.2989, being -48.715, is obtained for the intersection of SD and level 1. For the intersections of SD and levels 2 and 3, the averages are obtained as -51.671 and -54.253, respectively. These are respectively calculated from the average of -51.7807 and -51.5613 for level 2 and the average of -54.3553 and -54.1508 for level 3 of their intersections with SD. However, in finding the delta values, only two items out of three are considered for parameter W. this makes only two entries available for different measures. Here, the delta value is the difference between -57.4224 and -51.6703 to yield 0.247944.

By following similar steps for Part B in Part C, where the cut-off is now 59% and 55.53675% is the actual cut-off based on our data, while only trials 1 to 5 are included. In evaluating the values of levels 1, 2 and 3 for NL, with the Part C of the Taguchi-ABC method in focus, the averages obtained from the corresponding signal-to-noise ratios are rewarded in the response table (Table 5).

Table 5. Response table for Part C of the Taguchi-ABC scheme.

	Factors			
Level	W	NL	SS	SD
Level 1	-51.4224	-51.1409	-48.1311	-48.715
Level 2	-51.7248	-50.5398	-52.9657	-51.7807
Level 3	0	-54.3553	-51.8271	-54.253
Delta	0.3025	3.816	4.8347	5.5381
Ranking	4^{th}	3^{rd}	2^{nd}	1^{st}

Note: Optimal parametric settings: $W_1NL_2SS_1SD_1$

Commencing the computation of the cell containing the intersection of W and level 1, the average of only two SNRs, namely, -48.1311 and -54.3553, is sought for, yielding -51.4224. For the cell of the intersection of W and level 2, -54.1508 and -49.2989 are averaged to obtain -51.7248. However, there is no entry for the W and level 3 intersection since the 55.53675% cut-off has removed all the possible entries. Now, moving to the intersection of NL and level 1, the average of -48.1311 and -53.1508 is obtained as -51.1409; for the intersection of NL and level 2, the average of -51.7807 and -49.2989 is obtained as -50.5398. For the intersection of NL and level 3, only one entry is involved, which is -54.3553. Now, moving to SS, at the intersection of SS and level 1, only one entry is involved, which is -48.1311. At SS and level 2, the average of -51.7807 and -54.1508 is obtained as -52.9657. For level 3 and the intersection with SS, the averages of -54.3553 and -49.2989 are involved to yield -51.8271. Furthermore, for SD, the interaction of SD with level 1 yields an average between -48.1311 and -49.2989 to yield -48.715. For the SD and level 2 interaction, only -51.7807 is involved. For the SD and level 3 interaction, the average of -54.3553 and -54.1508 is obtained as -54.2530.

It is interesting to compare the ranking order for all methods. However, the strategy is to compare the ranking results of all the parts, i.e. parts A, B and C of the Taguchi-ABC method and then use the best performance as the benchmark to compare other methods, such as the Taguchi and Taguchi-Pareto methods. The ranked order of performance of the parameters for the wear performance of nylon6/boron nitride composite consists of the ranked parameters as each of the parameters, namely W, NL, SS, and SD, is compared with one another. The ranking order of alternatives according to part A of Taguchi-ABC and part B of Taguchi-ABC methods coincides with 4/4 alternatives, equivalent to 100%. For the comparison between parts A and C, the ranking order of alternatives according to part A of Taguchi-ABC and party C of Taguchi-ABC methods coincides with 4/4 alternatives, equivalent to 100%. For the comparison between parts B and C, the ranking order of alternatives according to part B of Taguchi-ABC and part C of Taguchi-ABC methods coincides with 4/4 alternatives, which may be equivalent to 100%. Now, since part A gives the same result as parts B and C, they are tied up. However, based on the coverage of the SNR percentage, part A, which covers 77.88142%, is chosen as the basis of comparison with the other methods. Now comparing, part A of the Taguchi-ABC and Taguchi-Pareto, they coincide with 4/4 alternatives, which is equivalent to 100%. Furthermore, the coefficient of determination that explains how the differences in the delta values of part A of the Taguchi-ABC method can be explained by the difference in the delta values of part B of part ABC method when predicting the optimal parametric setting of the wear process while producing nylon6/boron nitride composite was evaluated as 99.02%.

However, the coefficient of determination was obtained as 64.35%when part A of the Taguchi-ABC method is compared with part C of the Taguchi-ABC method. However, on comparing part B of Taguchi-ABC with part C of Taguchi-ABC, the coefficient of determination was obtained as 72.72%. In all three comparisons of the coefficient of determination, the relationship between part A and part B of the Taguchi-ABC method is the best. Now, each of parts A and B is compared with the Taguchi-Pareto method. First, the coefficient of determination of part A of Taguchi-ABC and Taguchi-Pareto is obtained as 100%, which is a perfect explanation. However, on comparing part B of Taguchi-ABC with Taguchi-Pareto, the coefficient of determination obtained is 99.02%, which is high. As a strategy to strengthen the quality of the present article such that an adequate understanding of the proposed method is made, the delta values obtained from the Taguchi-Pareto method are compared with that the delta values obtained from Boopathy et al. (2022). In this context, the coefficient of determination was made and obtained as 0.3586%. This is very low as it states that the Taguchi method utilized in Boopathy et al. (2022) cannot be used to explain the behaviour of the Taguchi-Pareto method.

3.3. Comparison of delta values for the Taguchi methods

In this work, the methods of Taguchi Pareto and Taguchi ABC have been used to analyze the parameters of the wear process namely the normal load, weight% particulate, sliding speed and sliding distance. However, it is important to show the relationship between these two methods and this was done with the use of the bar chart in Fig. 1.

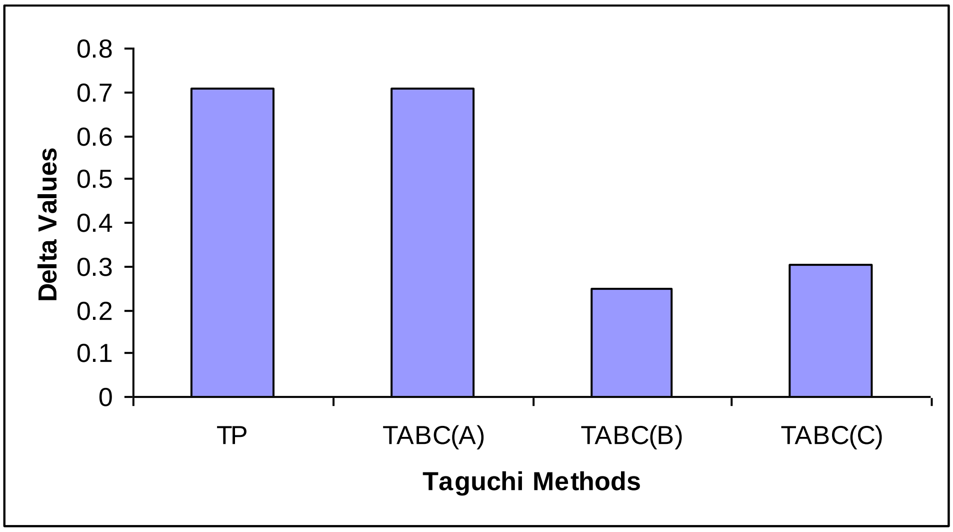

Fig. 1. Bar chart for delta values for all methods (TP, TABC(A), TABC(B), TABC (C)) for weight% of particulates.

To obtain these bar charts, the delta values are first derived from the response table. For each parameter, the delta values are then compared for all the methods, notably, Taguchi Pareto, Taguchi ABC (part A), Taguchi ABC (part B) and Taguchi ABC (part C). From the relationship of these methods with the delta values using the %weight, it was evident that both Taguchi Pareto and Taguchi ABC (part A) showed the highest value (i.e. 0.7062) while Taguchi ABC (part B) revealed the least value (i.e. 0.2479) (Fig. 1). The impression from this is that Taguchi Pareto and Taguchi ABC (part A) give better models than the rest of the methods since higher delta values are acceptable and attached to better methods. Furthermore, the linkages between the delta values and the Taguchi methods were examined (Fig. 2) and were implemented concerning the normal load (NL) as the parameter of interest.

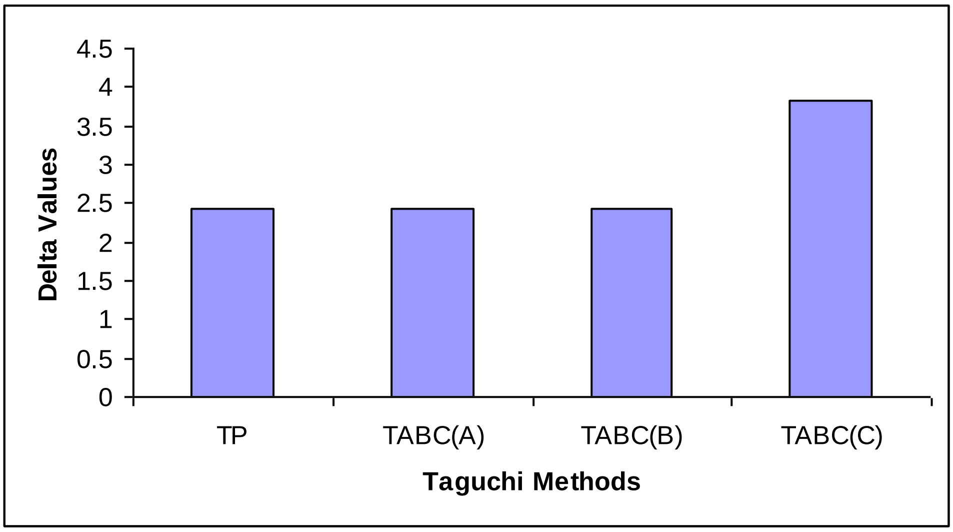

Fig. 2. Bar chart for delta values for all methods (TP, TABC(A), TABC(B), TABC(C)) for Normal load (NL).

The result from this association is that Taguchi ABC (part C) showed the highest delta value (i.e. 3.8155). A tie among Taguchi-Pareto, Taguchi ABC (part A) and Taguchi ABC (part B) occurred (i.e. 2.4185). Moreover, the association between the delta values and the Taguchi methods was analyzed (Fig. 3) and were implemented concerning the sliding speed (SS) as the parameter of interest.

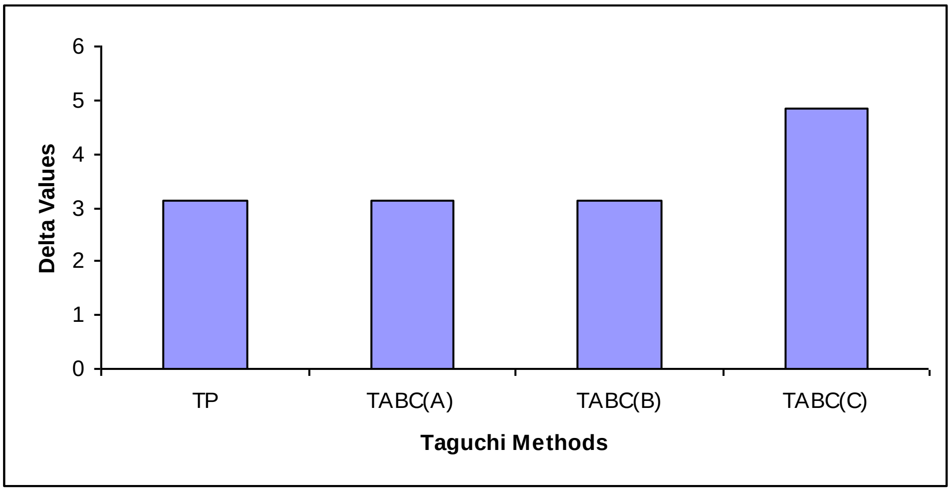

Fig. 3. Bar chart for delta values for all methods (TP, TABC(A), TABC(B), TABC(C)) for sliding speed (SS).

The result from this linkage is that Taguchi ABC (part C) showed the highest delta value (i.e. 3.1196). A tie among Taguchi-Pareto, Taguchi ABC (part A) and Taguchi ABC (part B) occurred (i.e. 4.8347). Then, the linkages between the delta values and the Taguchi methods were examined (Fig. 4) and were implemented concerning the sliding distance (SD) as the parameter of interest.

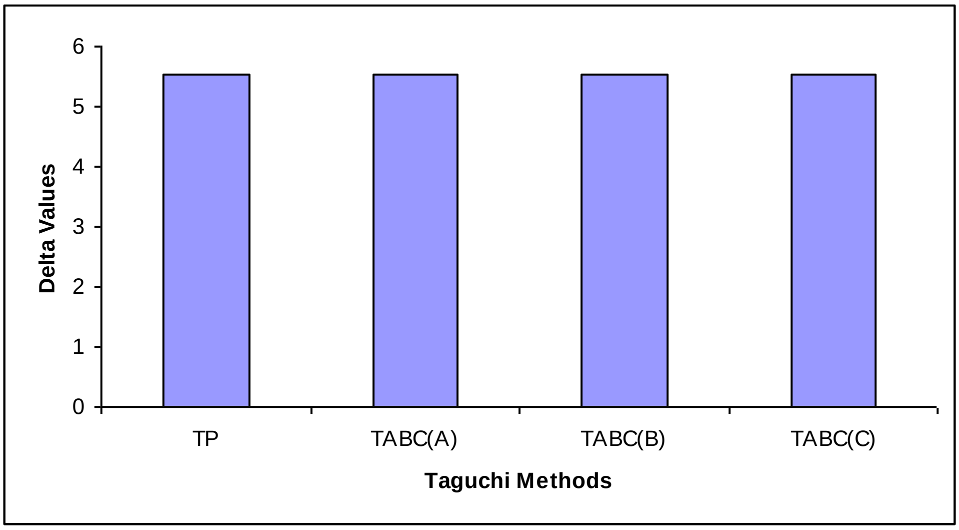

Fig. 4. Bar chart for delta values for all methods (TP, TABC(A), TABC(B), TABC(C)) for sliding distance (SD).

The result from this linkage is that all the Taguchi methods showed equal values of the delta values (i.e. 5.5381), indicating that there are no preferences among them.

3.4. Sensitivity analysis of parameters

In this article, four parameters, W, NL, SS and SD, were used to produce outputs, notably the optimal parametric settings, ranks of parameters and delta values of the average signal-to-noise ratios. However, in the previous part of this article, the Taguchi-Pareto method was tested for its effectiveness using the data on wear performance regarding mylonk/boron nitride composites. However, it is interesting to understand the responsiveness of each parameter to changes. Thus an extensive sensitivity analysis was launched to study the variations of W concerning the delta value changes to start the analysis. The analysis is referred to as scenario 1.

Scenario 1: NL, SS and SD parameters are constant, but only W, particularly experimental trial 1 and level 1, varies from 0 to 100% in steps of 10%. This means that W was fast retained as 4 and then varied as 4.4, 4.8, 5.2, 5.6, 6, 6.4, 6.8, 7.2, 7.6 and 8. It was noted that the changes do not affect the delta values of NL but affect the delta values of SS and SD.

4. CONCLUSIONS

In this study, two proposed methods, Taguchi-Pareto and Taguchi-ABC, were successfully tested and validated using the literature data from Kumar and Reddy (2020). The prioritization and optimization of the parameters were enabled by the Pareto and ABC mechanisms of the Taguchi-Pareto and Taguchi-ABC schemes, respectively. Moreover, sensitivity analysis was conducted by varying the % weight of reinforcement and holding the normal load, sliding speed and sliding distance constant. It was found that the optimal parametric setting of 4wt% of boron nitride nanocomposite, 15N of normal load, 100 rpm of sliding speed and 500m of sliding distance is achievable using the data from Kumar and Reddy (2020). The same result holds for the important part A of the Taguchi-ABC method. Consequently, this study provided a novel approach to optimizing and prioritizing the wear performance of nylon6/boron nitride nanocomposites. Future research is needed on extensive testing of the parameters in a sensitivity analysis. Also, extensions to the Taguchi-Pareto and Taguchi-ABC methods are warranted through weight introduction multicriteria methods.

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