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Research Article

Optimization on Tribological Behaviour of AA7178/Nano Titanium Diboride Hybrid Composites Employing Taguchi Techniques

Priyanka Chattoraj,[1] Parimala Prabhakar,[2] Vishwanath Koti,[3] N. Suganya Natarajan,[4] M. Lakshminarayana,[5] K. Arul,[6] M. Venkatachalapathy,[7] Maqusood Ahamed,[8] M. Karnan,[9] and S. Praveen Kumar[10]

[1]*Department of Mechatronics, Faculty of Science & Technology, ICFAI Foundation for Higher Education, Hyderabad, Telangana 500060, India*
[2]*Department of Electronics & Telecommunication Engineering, Ramaiah Institute of Technology, Bengaluru, Karnataka 560054, India*
[3]*Department of Mechanical Engineering, Ramaiah Institute of Technology, Bengaluru, Karnataka 560054, India*
[4]*Department of Civil Engineering, Sri Sairam Engineering College, Chennai, 600044 Tamil Nadu, India*
[5]*Department of Electronics & Communication Engineering, SJB Institute of Technology, Bengaluru, Karnataka 560060, India*
[6]*Department of Mechanical Engineering, Agni College of Technology, Chennai, 603 103 Tamil Nadu, India*
[7]*Department of Mathematics, K. Ramakrishnan College of Engineering, Tiruchirappalli, Tamil Nadu, India*
[8]*Department of Physics and Astronomy, College of Science, King Saud University, Riyadh 11451, Saudi Arabia*
[9]*Grassland and Forage Division, National Institute of Animal Science, Chungnam-do. 31000, Republic of Korea*
[10]*Department of Mechanical Engineering, Faculty of Mechanical Engineering, Arba Minch Institute of Technology (AMIT), Arba Minch University, Ethiopia*

Correspondence should be addressed to S. Praveen Kumar; praveen.kumar@amu.edu.et

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This article evaluates the effect of wear parameters on composite materials. Aluminium alloy 7178 alloys with various nano titanium diboride weight percentages were prepared using stir casting. A pin-and-disc test rig was utilized to carry out the dry sliding wear test. Using Taguchi's experiments for optimization, the L27 orthogonal array was designed (D.O.E.). The SNR and ANOVA techniques were used to identify the percentage of responses attributable to the input parameters. Both the wear rate and coefficient of friction increased with higher loading levels. This parameter, load intensity, had the most significant influence on wear rate and C.O.F. and sliding distance and velocity. Material removal was prevented at all times by nano titanium diboride particles embedded in the matrix alloy. AA7178 was treated with nano titanium diboride particles to improve its wear resistance.

1. Introduction

Modern manufacturing has relied on metal matrix composites for many years to replace the need for high-density materials [1]. As compared to other materials, aluminium matrix composites (AMCs) offer several advantages. Additional characteristics include having good wear and corrosion resistance, as well as a low thermal expansion coefficient. Using a variety of methods, one can create an assortment of AMCs [2]. All of these metalworking techniques—such as powder metallurgy (PM), stir casting (S.C.), and composite casting (CC)—are used in liquid infiltration (LI) [3]. For the homogeneous

Table 1: Different physical properties of nano titanium diboride (TiB_2) nano size particulates.

Physical appearance	Natural colour	Percentage of purity	Mass density (g/cc)	Size range of the particle
Powder form	Grey	98	5.63	50-60 nm

Table 2: Various chemical composition of aluminium alloy (AA7178).

Chemical elements	Chromium	Ferrous	Silica	Magnesium	Manganese	Copper	Zinc	Titanium	Al
Contribution in wt%	0.23	0.21	0.02	2.46	0.04	1.49	4.98	0.01	Balance

dispersion of ceramic particles, mechanical stirring is an inexpensive and simple solution [4].

A metal matrix composite is made up of matrix material and reinforcing particles. Stir casting is a process for fabricating composites in a liquid state. Matrix materials can be enhanced with a hard particulate material to improve their mechanical qualities [5–7]. In comparison to steel, aluminium matrix composites (AMCs) are much lighter, cheaper, and provide better mechanical and tribological properties [8–10]. Wear control factors were studied in these studies to see their effects on wear rate (i.e., reinforcements, loads, sliding distance, and slipping velocity). Wear rate is largely determined by load [11]. It is affected by sliding velocity, the level of reinforcement in the structure, and other factors [12]. The relationship between reinforcement volume fraction, grain size, and sliding distance is important because of abrasive wear [13]. The rate of wear was greatly affected by the volume fraction of reinforcement [14]. Hybrid Al/alumina/graphite AMCs have high wear and friction, according to a study. As the TiC content in the AA7178 composites increased, wear and C.O.F. decreased [15]. The wear resistance of an alumina 7075 alloy Ni premised composite was studied experimentally [16]. AA7075 composites incorporating Si3N4 particles produced by stir casting were studied to estimate the wear resistance and C.O.F. SiC reinforcement reduced the volumetric wear loss of Al7075/SiC AMCs [17]. Through the use of Al-Si3N4 nanocomposite materials, researchers discovered how stress, wear, and sliding distance influence COF. Wear rate and C.O.F. of hybrid composites were lower when compared to nanocomposite materials [18]. SiC and TiO2 particulate composites in aluminium alloy LM25 were studied on a pin-on-disc machine. When the TiO2 content increased, C.O.F. and wear rate decreased. TiO2 particles lubricate and harden, improving wear resistance [19].

On the other hand, TiS2-reinforced LM13 aluminium AMCs were exposed to liquid metal during a dry sliding wear test. According to the study, the load had the greatest impact on the rate of wear. Because of the higher surface damages, the morphology of the eroded surface showed more wear at high loads. Al/AlB2 composites were analyzed using Taguchi's wear parameters during dry sliding. Compared to unreinforced aluminium matrix composite, which is composed of a matrix of finely divided aluminium particles, it has better tribological properties [20]. A variety of TiB2 particles were used to reinforce Al7075/TiB2 aluminium matrix composites (0, 5, and 7.5 per cent). The microhardness and strength of TiB2 particles increase with increases in their weight percentages [21]. Material properties, particularly those involving mechanical strength, must be understood when using TiB2-reinforced aluminium metal matrix composites prepared through stir casting. Adding TiB2 particles also increased the composite's ultimate tensile strength, which is a measure of the overall strength of the composite. Load normal and reinforcement ratios are highly correlated with wear rate [22]. All these factors play a role in composites' wear behaviour. The use of statistics to assess the wear behaviour of AMCs can save time and money. They report on the wear and morphological behaviour of Al7178 alloy-nano titanium diboride particle-reinforced composites fabricated through stir casting technique, based on an extensive literature review and a thorough literature search. These Al7178 alloy/nano titanium diboride-reinforced test pieces were subjected to stir casting tests, which involved dry sliding wear as the drying method. Several variables, such as the weight, the sliding velocity, and the distance of sliding, were examined in experiments with a pin-on-disc apparatus. To locate the optimal wear and coefficient of friction settings, a Taguchi test was used for a composite sample [23, 24].

2. Materials and Methods

2.1. Matrix and Reinforcement Selection. Nanoparticles of TiB2 are used as reinforcement. Titanium diboride (TiB_2) is an excellent ceramic material with great strength and endurance, as seen by its comparatively high melting point, hardness, strength-to-density ratio, and wear resistance. Nano titanium diboride has the same chemical composition as Al7178 (see Tables 1 and 2. In the base matrix, nano titanium diboride particles of 50-60 nm size are mixed (0, 2, 4, or 6 per cent).

2.2. Composite Specimen Preparation. A liquid state stir-casting technique is used to produce Al7178 aluminium alloy and nano titanium diboride. Previous research guided the researchers' conclusions, and thus, they claim that the metal matrix created through stir casting is of a higher quality than other fabrication methods. Figure 1 shows how to properly set up for stir-casting fabrication. To melt large Al7178 aluminium alloy ingots, a graphite crucible was heated for 20 minutes at 450 revolutions per minute in a gas burner (rpm). Using a muffle furnace, titanium diboride particles are heated to 600°C before being mixed with oxygen to remove oxides before being mixed. When aluminium is first melted, 0.5 wt% of nano magnesium is added to

Figure 1: Stir casting fabrication setup.

improve wettability, which leads to better mixing. It is used for stirring in the induction furnace. Table 3 reveals the pure and aluminium alloy composite specimen's composition details.

2.3. Dry Slide Wear Test Setup. The wear tests were done using a pin-on-disc apparatus (Figure 2). An EN31 steel disc was used to test P.O.D. wear. At constant sliding speeds of 4000 rpm and different applied loads of 15, 25, and 35 N, non-lubricated wear tests were carried out on each specimen over sliding distances of 750, 1500, and 2250 metres, respectively.

Before testing, pin samples were rubbed with emery paper to ensure effective contact between flat surfaces and steel discs. An electronic scale with a high degree of accuracy (less than 1 g) is used to measure the sample weight after it has been cleaned thoroughly with acetone solution. Weight loss serves as a point of reference when working out the rate of wear. When it comes to weight loss, you should wear attention to the amount of volume you shed for each inch of sliding distance. The surface morphology of the pins is examined with a scanning electron microscope after they have been subjected to a wear test.

2.4. Taguchi Optimization—Experimental Plans. To research and model the impact of process variables on response variables, we use the D.O.E. design technique. Application load, sliding velocity, and sliding distance were used in this study to estimate wear parameters. In Table 4, you will find a listing of parameters and intensity levels. In Taguchi experiments, L27 orthogonal arrays are employed. Orthogonal arrays must be used when the degree of freedom is less than or equal to the wear parameters.

In this study, we used a 27-row, 13-column orthogonal array. Each factor's level, the desired experimental resolution, and any cost limitations all play a role in the design of orthogonal arrays. The Taguchi model led to 27 experiments. This shows how the model reacted to wear and coefficient of friction. In an orthogonal array, there are five columns. There are five columns of data in the table for the sliding distance. The applied load is situated in the first column, slide speed in the second, and sliding speed in the fifth. This design is intended to help reduce wear and coefficient of friction. The final result table is made available (ANOVA). To measure the signal-to-noise ratio, you must choose a measurement type (for example, based on characteristic type). It is based on the following assumption: "Smaller is better." The signal-to-noise ratio is measured in the laboratory. A logarithmic transformation was applied to reduce the response loss.

Table 3: Pure and aluminium alloy composite specimen's composition details.

Designation of composite specimen samples	Weight percentage of matrix material (AA 7178)	Weight percentage of reinforcement material (nano TiB_2 + nano Mg)
AAT0	100	0
AAT2	98	2
AAT4	96	4
AAT6	94	6

Figure 2: Wear testing setup.

Table 4: Optimization parameters with levels.

Optimization plan level	Wear load (N)	Sliding velocity (m/s)	Sliding distance (m)
1	15	1	750
2	25	2	1500
3	35	3	2250

3. Results and Discussions

3.1. Tribological Behaviour of Composites. $AA7178/TiB_2$ aluminium matrix composite reinforced with titanium diboride particulates exhibits different tribological behaviours depending on their weight percentage in dry sliding wear test apparatus. Using the stir casting method, composite specimens were poured into moulds. Four different

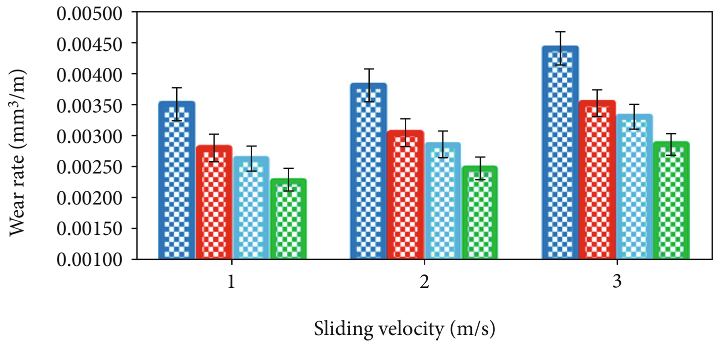

Figure 3: Comparison of wear rate in pure and hybrid composite materials depending on sliding velocity.

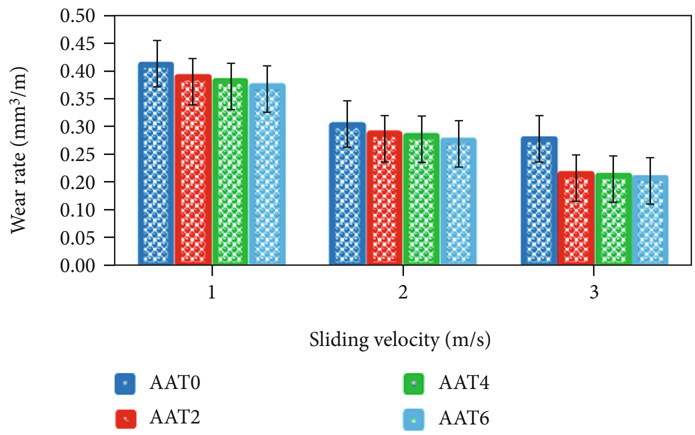

Figure 4: Coefficient of friction for pure and hybrid composite specimens varies with respect to the sliding velocity.

composite specimens were subjected to a range of sliding distances to simulate a dry sliding wear test. Varying weight percentages produce varying wear and C.O.F. for these composites when considering sliding velocity. The rate of wear and the C.O.F. both increase as sliding velocity increases.

Aluminium alloy 7178 and Al7178-6 wt percent titanium diboride composites show maximum and minimum wear rates at a sliding velocity of 1 m/s is shown in Figure 3. With an increase in sliding velocity, the temperature difference increases between the pin's surface and the counter disc. This type of heat can be damaging to your health. So, the rate of wear will be impacted by this. The wear of the pin increases as the temperature of the pin is raised.

Figure 4 reveals the coefficient of friction for pure, and hybrid composite specimens vary with respect to the sliding velocity. With increasing loads and other input factors remaining constant, the pin sliding surface's asperities become deformed, resulting in a very smooth surface layer that produces a high flash temperature. Coefficients of static and dynamic friction increase when sliding velocity increases, while they decrease when sliding velocity decreases. Al7178, an 80-per cent mix of the Al7178-Titanium Diboride composite, produces a mechanically mixed layer when compared to the Al7178-Titanium Diboride composite composites, which promotes the removal of material during sliding. When the sliding pin comes in contact with the counter disc plate, enormous pressure is applied to the contact velocity. It is the maximum sliding velocity of a surface that causes a build-up of frictional heat, which raises the surface temperature and accelerates the formation of oxide layers.

3.2. Results of Statistical Analysis of Experiments. In a variety of parameter combinations, the orthogonal array method was used. Minitab 16 was developed specifically for D.O.E. applications and is commercial software. When measured using the L27 orthogonal array, composite AAT6 showed superior tribological properties (see Table 5). AAT0, AAT2, and AAT4 are available. Delamination and increased wear are common problems when materials are not reinforced with hard reinforcement materials. A recording's signal-to-noise ratio (SNR) determines its quality (SNR). Wear and C.O.F. were found to be affected by the load, sliding speed, and friction coefficient by using an S/N response table. Sliding speed and distance are critical to wear rate and friction coefficient. For instance, a bar graph illustrating the rate of wear or a table illustrating the C.O.F. are all good examples of this type of illustration. Using the S/N ratio as a guide, it is possible to identify the conditions under which the wear rate and C.O.F. are at their lowest. If P2 is equal to 20 Newtons, V3 is equal to 3 m/s, and S3 is equal to 2250, the answer is "yes." Wear and C.O.F. were found to be affected by load, sliding speed, and friction coefficient by using an S/N response table. Sliding speed and distance are important in terms of wear and friction coefficient. This

Table 5: Taguchi orthogonal array for AAT6 hybrid composite (94 wt.%AA7178 + 6%TiB_2).

Exp. no.	Wear load (N)	Sliding velocity (m/s)	Sliding distance (m)	Wear rate (mm^3/m)	S/N ratio (db)	CoF	S/N ratio (db)
1	10	1	750	0.00356	48.785	0.412	8.6547
2	10	1	1500	0.00399	47.809	0.379	9.5202
3	10	1	2250	0.00395	46.853	0.341	10.4722
4	10	2	750	0.00391	51.070	0.321	11.5194
5	10	2	1500	0.00387	50.049	0.301	10.3675
6	10	2	2250	0.00383	49.048	0.283	10.6626
7	10	3	750	0.00379	48.557	0.312	11.7288
8	10	3	1500	0.00376	47.586	0.343	11.8650
9	10	3	2250	0.00372	46.634	0.377	11.6116
10	20	1	750	0.00280	50.983	0.314	11.9421
11	20	1	1500	0.00322	49.963	0.295	9.4920
12	20	1	2250	0.00319	48.964	0.278	10.4504
13	20	2	750	0.00316	47.985	0.396	10.6285
14	20	2	1500	0.00312	47.025	0.330	10.4412
15	20	2	2250	0.00309	49.376	0.301	9.9279
16	20	3	750	0.00306	51.845	0.283	10.7479
17	20	3	1500	0.00303	46.661	0.404	10.6785
18	20	3	2250	0.00243	52.260	0.264	12.5392
19	30	1	750	0.00263	51.025	0.384	11.2717
20	30	1	1500	0.00289	45.923	0.290	11.4972
21	30	1	2250	0.00318	41.331	0.345	11.7271
22	30	2	750	0.00314	45.464	0.269	11.9617
23	30	2	1500	0.00311	50.010	0.296	12.2009
24	30	2	2250	0.00308	45.009	0.326	10.3708
25	30	3	750	0.00305	49.510	0.290	9.3337
26	30	3	1500	0.00302	47.034	0.319	10.1674
27	30	3	2250	0.00299	39.979	0.284	10.3708

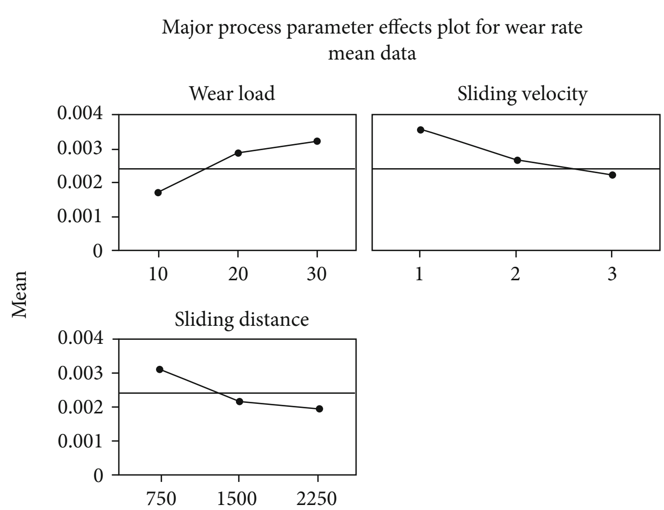

Figure 5: Wear Rate Main Effects plot for Means (AAT6 Composites)

type of illustration could be considered an example of the visual element known as an illustration: a bar graph that illustrates the rate of wear or a table that illustrates the C.O.F. When the S/N ratio is used as a guide, then, it is possible to locate the condition that minimizes wear and coefficient of friction. Yes, if P2 is equal to 20 Newtons, V3 is equal to 3 m/s, and S3 is equal to 2250. Results obtained using an S/N response table have shown that parameters

Table 6: Optimization response table for signal to noise ratios—smaller is better (wear rate AAT6 hybrid composites).

Optimum levels	Sliding load (N)	Sliding velocity (m/s)	Sliding distance (m)
1	51.84	52.26	51.07
2	50.98	51.02	49.96
3	50.08	51.36	49.51
Delta	4.21	3.21	2.64
Rank	1	2	3

Table 7: Optimization response table for signal to noise ratios—smaller is better (coefficient of friction—AAT6 hybrid composites).

Optimum levels	Sliding load (N)	Sliding velocity (m/s)	Sliding distance (m)
1	11.611	10.477	10.747
2	11.865	11.961	10.441
3	11.519	10.37	9.927
Delta	0.782	0.679	0.596
Rank	1	2	3

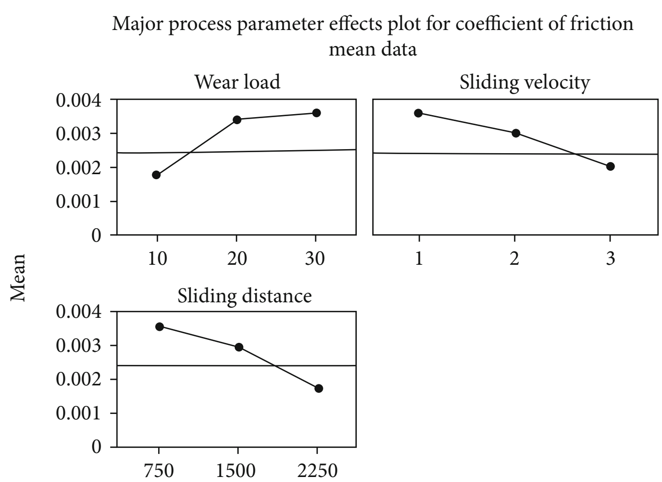

Figure 6: C.O.F.—main effects plot for means (AAT6 composites).

such as load, sliding speed, and friction affect wear and C.O.F. Sliding speed and distance significantly affect the wear rate and friction coefficient. Another illustration of this type would be a bar graph or table illustrating the rate of wear, and a third is a linear graph or equation showing the C.O.F. S/N ratio can help in determining the specific conditions under which wear and coefficient of friction are at their lowest. In this case, the answer is "yes." If P2 is equal to 20 Newtons, V3 is equal to 3 m/s, and S3 is equal to 2250.

3.3. Analysis of Variance Results for Wear Test. Figure 5 reveals the wear rate main effects plot for means (AAT6 composites). A variance analysis was performed on the experimental data in order to determine the effect of wear parameters on performance measures. ANOVA reveals which independent variable is dominant and what percentage of variance is attributable to that independent variable, based on the results of an experiment. Three factors are variable on three levels and interact with each other, according to new research. The results of the analysis of variance for wear rate and coefficient of friction are provided in Tables 6 and 7. Based on ANOVA, the amount of load has a larger impact on wear rate and C.O.F. than any other single factor. Charge, sliding speed, and distance are all related to wear. We found that the sliding speed and the distance, as well as load interactions, had negligible effects on sliding speed and distance. Figure 6 reveals the C.O.F.—main effects plot for means (AAT6 composites).

"All hybrid aluminium alloy composite specimens had pooled errors of less than 2 per cent" in the ANOVA table for wear rate and C.O.F., according to the study. Applying a load causes wear and C.O.F. to increase. Friction is proportional to wear rate; the higher the applied load and the higher temperature. As a result, the reinforcing particles do not degrade during wear, due to the increase in stress caused by increasing load, material fractures as a result. Due to friction between fractured reinforcing particles and steel discs, there is a possibility that material will be transferred from pin to disc. In addition, when the pin is loaded, it loses more material from its surface as a result of the load.

The wear rate and C.O.F. both decrease as the sliding speed increases. As well as reducing sliding and wear, the interfacial region is also responsible for controlling the oxidation temperature of aluminium alloy. The sliding distance increases the wear rate and C.O.F. Abrasion resistance and dry sliding wear performance are improved as a result of the new coating technology used in this application. Due to their self-lubricating property, aluminium composites with reinforcement have improved friction and wear properties. Sliding pins have a layer of reinforcement on the surface, reducing wear.

4. Conclusions

(i) The AA7178 alloy is reinforced with nano titanium diboride particles fabricated via stir casting method and analyzed the effect of wear parameters like wear load, sliding velocity, and sliding distance. To improve the process control of the stir casting matrix, we implemented the nano titanium diboride (NTDB) powder addition that contains 2, 4, and 6 weight percent of Al7178

(ii) To decrease the wear rate and coefficient of friction by optimizing the control parameters for composite materials' dry sliding wear behaviour. No practical upper limit exists for the amount of wear when the sliding velocity is 3 m/s, and the sliding distance is 2250 m. Sliding mass: 20 kg; velocity of sliding: 1 m/s; length of sliding: 1500 m; maximum coefficient of friction

(iii) Wear and friction coefficient were affected by load and sliding distance, according to a variation analysis (ANOVA). Composites wear out faster due to load and sliding distance. To improve the wear resistance, nano titanium diboride (NTDB) is added as an additive

(iv) Due to the high resistance to wear, metal composites reinforced with nano titanium diboride particles (the dry sliding wear behaviour of alloy composites) have shown particular interest for engine components like piston rings, cylinders, and bearings

(v) These optimization methods may be used to optimize further the composite's wear rate parameters: particle swarm optimization, genetic algorithms, and other approaches like that

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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