Novel Dragonfly-assisted Black Widow Optimization Strategy to Enhance Si_3N_4 Wear Performance

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Rebuilding injured joints with appropriate substitute materials is an important requirement for treating individuals with arthritis. Aseptic loosening is a major problem due to the wear particle production that occurs during movement in artificial joints. Finding materials with the least amount of wear volume loss is the goal of biotribology research to increase joint longevity. One ceramic material that shows promise as a substitute for hip and knee replacements is silicon nitride (Si3N4). As a solid lubricant additive, Hexagonal Boron Nitride (hBN) may improve Si3N4 wear performance. With the goal of minimizing wear volume loss (WVL), this research evaluates the ideal load and hBN volume percentage in Si3N4. A mathematical model is informed by the experiments, which are carried out using the Design of Experiments (DoE) - Taguchi approach. In order to find the ideal hBN % for minimising wear volume loss against an Alumina (Al2O3) counterface, the model is processed by Dragonfly-assisted Black Widow Optimisation (DA-BWO). Taguchi technique finds 12 N load and 6% hBN volume, but DA-BWO optimization offers 10.632% hBN volume and 9.75 N load to minimise wear volume loss of Si3N4.

Keywords: Si3N4, Hexagonal Boron Nitride (hBN), Design of Experiments (DoE), Taguchi Method, Dragonfly-assisted Black Widow Optimisation (DA-BWO).

1. Introduction

Silicon nitride (Si3N4) is a versatile and promising ceramic with remarkable mechanical and thermal characteristics in the field of advanced materials. Si3N4, which is widely used in many different sectors, has proven to be a dependable choice for applications demanding robust wear resistance (Heimann 2021). As industries strive for enhanced performance, the current emphasis in research and development endeavors is directed toward optimizing the wear performance of Si3N4 (Li et al 2021). Silicon nitride is widely recognized for its exceptional hardness, strength, and resistance to thermal shock, making it a material of choice for diverse applications ranging from precision bearings in industrial equipment to state-of-the-art aircraft components. Due to contemporary engineering and technology, its wear resistance must be improved (Ouyang et al 2022). Si3N4 wear performance is improved by integrating material science, surface engineering, and nanotechnology (Ramezani et al 2023). To increase Si3N4's mechanical properties, researchers are exploring new grain boundaries and composition changes. Pressure lesssintering and hot isostatic pressing need careful observation to change the material's structure for wear resistance (Benito et al 2021). To improve Si3N4 wear performance, surface modification approaches are becoming more common. Si3N4 is coated with protective material thin layers using cutting-edge PVD and CVD methods. These coatings prevent wear and extend Si3N4 component life in demanding circumstances (Kaloyeros et al 2020).Nanotechnology is quickly developing nanoparticle integration into Si3N4 matrices to create wear-resistant nanocomposites (Siripongpreda et al 2022). By including nanoscale reinforcements, such as carbides or nitrides, Si3N4 may gain toughness and hardness, strengthening its resistance to abrasion and wear. The pursuit of enhancing the wear performance of Si3N4 remains an active and evolving field, driven by continuous changes in industries and the demand for materials capable of withstanding harsh environments (Zhai et al 2021). Xing et al(2022) optimized the tribological characteristics of Si3N4/TiC ceramics by examining the effects of wear efficiency, adhesion, and friction through the combined use of DLC coatings and dimpled surface textures. DLC coatings are deposited used plasma-enhanced chemical vapor deposition, while surface patterns in the form of dimples are produced on Si3N4/TiC ceramics using a nanosecond laser. The results of the study show that Si3N4/TiC ceramics have much improved wear and friction characteristics; the most notable improvement is shown when DLC coatings are paired with dimpled textures.

Rondinella et al(2019) surface pre-oxidation affects silicon nitride (Si3N4) ceramic wear in prosthetic femoral heads made of “ultra-high molecular weight polyethylene (UHMWPE)” in dry and moist settings. Held controlled studies on Si3N4ceramic heads and UHMWPE spherical pins to investigate how surface pre-oxidation impacts wear and degradation. Pre-oxidizing Si3N4heads form a silica and orthosilicate layer in the lubricated tribolayer, enhancing Si3N4/UHMWPE couple performance and reducing UHMWPE oxidation under wet conditions. Since it was conditional, the study may not fully reflect prosthetic hip joint application issues. Wang et al(2022) Si3N4ceramics with tungsten particles (0 and 5 vol%) wear resistance. Gas pressure sintering produced commercial Si3N4ceramic balls for wear testing. The tribo-film is formed by rubbing exfoliated and oxidized tungsten particles. Tungsten particles cut abrasive, oxidative, and surface fatigue better than monolithic Si3N4. Wear rate decreased tenfold, from 4.70×10^{-6} to 3.78×10^{-7} $mm^3 N^{-1} \cdot m^{-1}$. Tungsten particles cut abrasive, oxidative, and surface fatigue better than monolithic Si_3N_4. Oguntuyi et al (2022) investigated the silicon nitride affects the mechanical properties, sinterability, densification, & wear behavior of composites made of (TiB_2-105SiC) and (TiB_2-80%SiC). Adjust the Si_3N_4percentages, examine the microstructure, and take measurements of the hardness, fracture toughness, and density. Examine the resultant composites' wear characteristics. With 2.5% Si_3N_4, TiB_2–20SiC composite reached its ideal characteristics, showing increased wear resistance. Density and hardness were decreased in composites with higher Si_3N_4(5%).Lin et al (2021) effort aimed to add a Si_3N_4@MoS_2 core-shell structure to epoxy resin/polyacrylate interpenetrating polymer network (IPN) composite coating to increase its resilience to abuse and corrosion. A composite coating, including the Si_3N_4@MoS_2 core-shell structure, was applied. Experiments were conducted to assess corrosion resistance and wear. Si_3N_4@MoS_2 core-shell structure efficacy was shown by the composite coating, which offered improved wear and corrosion resistance. Tan et al (2020) explored optimizing phase composition and microstructure leads to the creation of a high-performance silicon nitride (Si_3N_4) ceramic cutting tool. 4.9 wt% to 49.7 wt% of varying α-Si_3N_4concentration in the Si_3N_4ceramic tool tested cast iron for continuous cutting and evaluated its hardness. Tool life increased from around 1200 m to approximately 2400 m when the α- Si_3N_4concentration was greater, which is explained by better adhesive and abrasive wear resistance. Reduced fracture toughness caused by a higher α- Si_3N_4 concentration increased the likelihood of chipping. Enhanced performance is achieved by reinforcing with an elongated β- Si_3N_4phase.

Liu et al (2022) improved high-temperature ceramic tribological characteristics to reduce wear and friction in operating mechanical systems. At 800 °C, SEM, TEM, and Raman spectra on worn surfaces studied the tribological properties of a Sn-containing Si_3N_4-based composite. At 800 °C in air, the composite exhibits outstanding tribological characteristics, with friction coefficient as well as wear rate decreased to 0.27 and 4.88×10^{-6} mm^3 N^{-1} m^{-1}. Also identified the wear process at different temperatures and tribo-driven graphitization on worn surfaces and debris with carbon. Pulse-current electroplating Ni–Co–P/ Si_3N_4composite coatings on Al–Si substrates improves adhesion (Li et al 2022). Measure microstructure, mechanical, and tribology. Rapid Ni–Co intermediate layer deposition via pulse-current electroplating. Assessed mechanical and tribological properties and microstructure. Highly crystalline Ni–Co sosoloid, P, and 7.65% Si_3N_4composite coating. Doubled Al–Si hardness. Very good anti-wear performance in dry and lubricated circumstances. Limited to electroplated coatings; need further research for particular applications and durability.Li et al(2021) examined how silicon nanoparticles affected the time water-lubricated Si_3N_4ceramics required to operate. Using a scanning electron microscope and an optical microscope, examine ceramic wear surfaces at various phases of experimentation. Examine running-in “coefficient of friction (COF)” patterns. On the worn surface, nanoparticles produce a homogenous layer that dynamically covers and balances it. Despite considerable successes, there is a lack of knowledge of the nanoparticle running-in period reduction process.Llorente et al (2020) tribological behaviour of Si_3N_4ceramics utilising a two-step method that includes SiCn composites and graphene-based fillers. Create Si_3N_4/SiC composites with different SiCn concentrations and then add 11 vol.% of GNPs or rGOs. Conduct testing using isooctane lubricant and in dry circumstances. Si_3N_4/SiCn composites may lower friction coefficient and wear rate up to 22% and 40%, respectively.

rGOs composite has a 50% decrease in friction and a 44% increase in wear resistance. The study's focus was restricted to Si3N4 ceramics, and more research may be required for wider applications and materials.

The goal is to improve the wear performance of Si3N4materials by creating a new Black Widow Optimisation Strategy with the help of Dragonflies. This novel method achieves exceptional durability by combining black widow and dragonfly biomimicry, offering a special and practical way to maximise Si3N4wear resistance.

2. Methodology

Experiments were conducted utilizing the DoE - Taguchi method then a model based on mathematics was established. Subsequently, Dragonfly-Assisted Black Widow Optimization (DA-BWO) was applied to the developed model to determine the ideal hBN content in Si3N4, with the goal of reducing wear volume loss in comparison to an Al2O3 (alumina) counterface.

2.1 Dragonfly-assisted Black Widow Optimization (DA-BWO)

The study uses Dragonfly-assisted Black Widow Optimization to examine the wear performance of Si3N4, a silicon nitride ceramic. This novel method optimizes the wear properties of Si3N4by integrating bio-inspired algorithms that imitate the hunting habits of dragonflies and black widows. The study intends to improve the wear resistance and durability of the material by utilizing the synergies between biological inspiration and computer optimization. Dragonfly-assisted Black Widow Optimization presents a new and possibly useful approach to improve Si3N4wear performance in various industrial settings. Dragonfly Algorithm (DA) is a population-based metaheuristic algorithm that simulates dragonfly hunting and migration. Dragonflies hunt in tiny groups in a static swarm that mimics nature. The algorithm's optimization process is reflected in bigger dragonfly groups' coordinated movement, forming a dynamic swarm.

2.1.1 Dragonflies swarm using five operators

Separation makes search agents apart throughout the neighborhood. The mathematical model of separation behavior is provided in Equation (1).

$$S_j = \sum_{i=1}^{n} y - y_i \qquad (1)$$

Alignment compares the velocity of a search agent to peers in the vicinity. Mathematical modeling of alignment behavior is illustrated in Equation (2).

$$A_j = \frac{\sum_{i=1}^{n} v_i}{n} \qquad (2)$$

Cohesion refers to the movement of persons from the neighborhood to the center of mass. Individuals tend to gravitate towards the nearby center of mass. Cohesion is modeled mathematically in Equation (3).

$$C_j = \frac{\sum_{i=1}^{n} y_i}{n} - y \qquad (3)$$

The term "attraction" refers to how the food supply draws the individuals who fly towards it. Equation (4) depicts the mathematical description of this phenomenon.

$$F_j = F_{loc} - y \qquad (4)$$

where F_{loc} denotes the location of the food supply.

Individuals' tendency to flee from an enemy is referred to distraction. Equation (5) mathematically models the diversion between the j^{th}solution and the adversary.

$$E_j = E_{loc} - y \qquad (5)$$

Where E_{loc} represents the enemy's location.

Using the candidate with the greatest fitness, the fitness of the food source and location are updated throughout the search process in DA. Furthermore, the poorest candidate updates the opponent's fitness and location. This causes a shift toward good search locations and away from bad search areas.

A novel and fascinating meta-heuristic technique for complex numerical optimization problems is Black Widow Optimization (BWO). BWO is an evolutionary algorithm like Genetic Algorithms. BWO follows selection, reproduction, and mutation but adds criteria inspired by black widow spider mating behavior. BWO, inspired by Darwin's theory of natural selection and stressing descent with modification, outperforms evolutionary algorithms in difficult tasks. BWO is a powerful approach for handling optimization problems with many local optima due to its fast convergence and local optima avoidance. Figure 1 flowchart shows the algorithm's careful mix of exploration and exploitation.

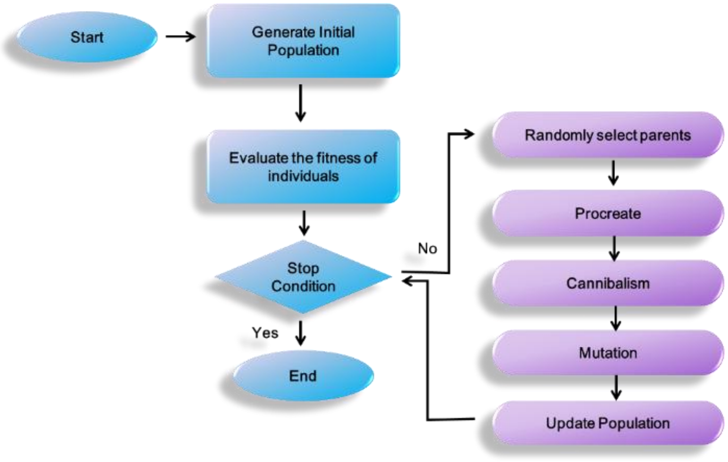

Figure 1Structure of BWO [Source: Author]

2.1.2 Description of BWO key steps

Initializing: The population in this phase consists of widows, each represented as a 1 × N_{var} array(widow $= (x_1, x_2, \ldots, x_{N_{var}})$), where Nvar is the optimization problem dimension. The procedure requires N_{var} threshold values, and xi is the i-th candidate solution. Our suggested technique evaluates the fitness function (fitness $= f(x_1, x_2, \ldots, x_{N_{var}})$) to calculate each widow's fitness. Otsu Equation 6 or Kapur Equation 7 can be substituted. To start the optimization process, a spider population is randomly initialized in a $N_p op \times N_v ar$ matrix. Then, pairs of parents are randomly picked for reproduction, and the female black widow consumes the male during or after mating.

$$f_{Otsu}(TH) = \max\left(\sigma_b^2(th)\right) \tag{6}$$

$$f_{Kapur}(TH) = \sum_{j=1}^{k} h_j \tag{7}$$

Pro-Create: A random widow array with numerical values and an alpha (α) array are formed during the procreation process. The offspring is formed using α and Equation 8, with parents A_1 and A_2 and offspring B_1 and B_2. For subsequent study, the crossover result is analyzed and stored.

$$B_1 = \alpha \times A_1 + (1-\alpha) \times A_2 \text{ and } B_1 = \alpha \times A_2 + (1-\alpha) \times A_1 \tag{8}$$

Cannibalization: Spiders consume their mothers, although cannibalism can be sexual, sibling, or other. A variable named pop2 stores the new population after cannibalism.

Mutations: The mutation process is carried out by selecting the Mutepop number of individuals from the population that will be modified. Each of the solutions suggested swaps two array members at random. Following the application of mutation, the new population is assessed and stored in the new population, pop3. Finally, the new population may be produced by combining pop3 and pop2, which is sorted to yield the best widow of threshold values with Nvar dimension.

Dragonfly-assisted Black Widow Optimization (DA-BWO) is a hybrid metaheuristic algorithm that combines the capabilities of the Dragonfly Algorithm (DA) and Black Widow Optimization (BWO) to improve the optimization process. The coordinated movement of dragonfly swarms from DA is included in this hybrid technique to direct the exploration and exploitation stages of BWO. Separation, alignment, cohesion, attraction, and distraction operators from DA impact the creation and behavior of the black widow population in BWO. The synergistic combination of these algorithms takes the use of dragonfly exploring skills and black widow spider convergence and local optima avoidance, resulting in a robust and efficient optimization process. The hybrid method's mathematical formulation Equation 9 is follows:

$$w_j^{(t+1)} = \beta \times DA\left(w_j^{(t)}\right) + (1-\beta) \times BWO(w_j^{(t)}) \tag{9}$$

Were $w_j^{(t+1)}$reflects the modified solution for the $i-th$ widow at iteration $t+1$, $DA\left(w_j^{(t)}\right)$and $BWO(w_j^{(t)})$ are the solutions given by the Dragonfly method and Black Widow Optimization for widow i at iteration t, respectively, and β is a weighting parameter that specifies the effect of each method on the hybrid solution. This method seeks to use the complementary qualities of DA and BWO to enhance optimization performance across a wide variety of complicated numerical problems. Table 1 illustrates the best values for each component in the DA-BWO simulation, demonstrating the effectiveness of the method. Meanwhile, the optimum fitness plot is shown in Figure 2, which provides a graphic depiction of the optimization process and demonstrates the algorithm's effectiveness in identifying the best options. Table 1 and 2 illustrates the optimal force and % volume of hBN, DA-BWO and Taguchi analysis minimise Si_3N_4 wear volume loss against an aluminium counter face.

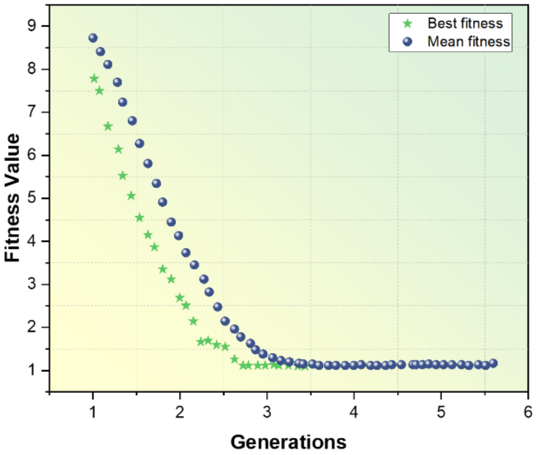

Figure 2Optimal performance graph [Source: Author]

Table 1Optimal parameter setting and Performance measure [Source: Author]

Force(N)	**Volume of hBN %**	**Performance Metric-WVL (mm^3/m)**
9.75	10.632	0.00752

Table 2Optimal settings and associated Wear Volume Loss (WVL) [Source: Author]

Parameter	**Taguchi Analysis**	**DA-BWO**
Force(N)	15	14.932
% Vol. of hBN	8	10.705
WVL (mm^3/m)	0.0111	0.00915

2.2 Experiment

Experiments were conducted in accordance with the Design of Experiments (DoE) using the Taguchi method, assuring a methodical approach. Following that, a mathematical model was created to assess and interpret the experimental data, offering significant insights into the aspects under examination.

2.3. Method DoE-Taguchi

Genichi Taguchi invented the Taguchi method, an instance of DoE, to facilitate experiment design and study the impact of factors on process performance variability. Taguchi developed the orthogonal array experimental design, which includes considering process factors and their degrees of variation. It enables data collecting to identify product quality variables with little trial, saving time and money. Selecting the right orthogonal array requires knowledge about the number of parameters and levels. Table 3 displays the level of parameters and factors selected for the experiment.

Table 3Optimal settings and associated Wear Volume Loss (WVL) [Source: Author]

F (factors)	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
The volume of hBN %	3	6	9	12	0
Force(N)	4	8	12	16	20

Table 3 shows five force and volume levels of hBN. A well-designed L25 orthogonal array was chosen to perform an efficient experiment, reducing the number of needed experimental runs while allowing a full and systematic investigation of the parameter space.

2.4 Sample preparation

Using a ball mill, Si3N4-hBN composites were created with different hBN volume percentages (3%, 6%, 9%, and 12%) combined with Si3N4. Following the mixing procedure, the material is subjected to uniaxial hot-pressing at 30 MPa and then heated to 1600°C. Following this, a one-hour break is included into the procedure. In hot-pressing, polyvinyl alcohol was an adjuvant. It produced 10.5 mm diameter and 14.5 mm length samples. Figure 3 and 4 show the final samples as well as the alumina disc used for wear testing. Tables 4 and 5 provide a detailed overview of the material's density and disc-specific properties by displaying the parameters of alumina discs and the density characteristics of sintered samples.

Figure 3Sintered samples of Si3N4-hBN[Source:https://www.ijrte.org/wp-content/uploads/papers/v7i5/E1959017519.pdf]

Figure 4Alumina frictional plate [Source: https://i.ebayimg.com/images/g/W9AAAOSwuShjzHBI/s-l1600.png]

Table 4Sintered sample volumetric mass [Source: Author]

Sampling	**1 (The Volume hBN- 3%)**	**2(The Volume hBN- 6%)**	**3 (The Volume hBN- 9%)**	**4 (The Volume hBN- 12%)**	**5 (The Volume hBN- 0%)**
Density g/cm^3	1.87	1.87	1.82	1.73	2.08

Table 5Common characteristics of alumina disc [Source: Author]

Nomination	**Percentage of purity**	**Density g/cm^3**	**Maximum Service Temperature (°C)**	**Average surface roughness measured in micrometers (μm).**
aluminium oxide (Al_2O_3)	98.6%	2.98×10^3	1600	1.582

2.4 Mathematical formulation

The statistical program Minitab 17 was utilized to fit experimental data using a second-order polynomial equation. The final equations characterize wear volume loss and are represented in terms of control variables, determined via Taguchi orthogonal array experiments, Equation (10).

$$\mathrm{WVL}\ \left(\mathrm{mm}^3/\mathrm{m}\right) = 0.526 - 0.038 \times \mathrm{load(n)} - 0.059\% * \text{valume of hBN} + 0.00373 \times \mathrm{load\ (n)} \times \mathrm{load(n)} + 0.00368 \times \%\text{volume of hBN} \times \%\text{ volume of hBN} - 0.00401 \times \mathrm{load(n)} \times \%\text{ volume of hBN} \qquad (10)$$

2.5 ANOVA

“Analysis of Variance (ANOVA)” is a numerical method that divides dataset variance into components linked with various sources of variation to evaluate model parameter hypotheses. The ANOVA results for a model run with a 90.5% confidence level are shown in Table 6. Notably, the relevance of the model is shown by its P-Value, which is 0.031 (below 0.005). When the Variance Inflation Factor (VIF) is 1, it indicates that the predictors are associated and that multicollinearity is not present in the model.

Table 6ANOVA Results for Wear Volume Loss [Source: Author]

Source's	**Degrees of freedom**	**Adjusted mean squares**	**Contribution (%)**	**Sequential sums of squares**	**p**	**F**	**Adjusted sums of squares**
Force(N)	4	1.5525	28.76	6.210	0.031	2.75	3. 987
% hBN	4	1.223	22.63	4.892	0.048	3.15	4. 589
Force(N) % hBN	16	0.6554	48.61	10.486	0.017	1.51	8. 812
Total	24	-	100	21.588	-	-	-
Variance Inflation Factor (VIF) for all factors =1							

3. Results

Use of the "Ducom TRLE-PMH400 pin-on-disc tribometer for ASTM F732" wear testing with a 200 N normal force capacity (ASTM 2017). One alumina disk, revolving at 200 rpm, served as the counterface in the experiments, whereas the pin specimen was a composite. As the applied stress increased, the pin maintained stationary and slid against the alumina. The atmosphere was maintained throughout the trials, which were carried out in a dry, lubricant-free setting.

3.1 Analysis of Signal-to-Noise (S/N) Ratio

Two input parameters were used on a Pin-on-Disc tribometer to evaluate wear volume loss. Based on the wear track diameter, wear volume loss was computed for 25 minutes of sliding and 200 rpm disc speed. Table 7 displays an average wear loss of volume from 25 twice-repeated exams. Optimisation goal function Taguchi's logarithmic ratios were used to convert experimental data into S/N ratios. The conventional S/N ratios were SB, NB, and HB. Controllable factors were evaluated using the S/N ratio approach to reduce wear loss of volume for longer joint life. In this research, the S/N ratio was computed using the "Smaller the Better" technique for wear volume loss.

Note : "Smaller is Better (SB), Nominal is Better (NB), & Higher is Better (HB)"

$$(S/N)_{SB} = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{11}$$

$y_i$irepresents individual observations in this Eq (11). The total number of observations is given by n.

A greater S/N ratio value implies better performance, regardless of the performance characteristic category. Examining the response table of S/N ratios in this research, where the aim is to reduce wear volume loss, provide the best input parameters for the output feature. The optimal configuration with 12 N force and 6% hBN volume has 0.0098 mm3/m wear volume loss and 38.42755 dB S/N ratios, as shown in Table 7.

Table 7 Outcomes regarding wear volume loss and Signal-to-Noise (S/N) ratio [Source: Author]

Experiment. No.	**Force(N)**	**Volume of hBN%**	**Average Wear Volume Loss**	**S/N ratio in decibels (dB)**
1.	4	3	0.2543	11.54826
2.	4	6	0.1732	15.07148
3.	4	12	0.2147	13.28019
4.	4	16	0.0296	30.47519
5.	4	0	0.3912	8.65449
6.	8	3	0.1763	14.95592
7.	8	6	0.0137	36.44238
8.	8	12	0.1251	18.72212
9.	8	16	0.0177	35.77262
10.	8	0	0.9413	1.258194
11.	12	3	0.2876	10.30591
12.	12	6	0.0098	38.42755
13.	12	12	0.0907	20.06939
14.	12	16	0.0842	20.73399
15.	12	0	1.1185	-2.67561
16.	16	3	0.1836	14.37635
17.	16	6	0.4467	7.78675
18.	16	12	2.0321	-5.34432
19.	16	16	0.1814	14.49355
20.	16	0	0.2987	10.58239
21.	20	3	0.5874	5.44617
22.	20	6	1.9102	-4.71998
23.	20	12	0.3756	8.88483
24.	20	16	0.1404	17.42099
25.	20	0	3.6782	-10.19665

3.2 Outcome graph

In Minitab 17, the graph of interactions shows the minimum Wear Volume Loss (WVL) at Figure 5 shows the greatest S/N ratio at 12 N Force and 6% hBN volume, whereas Figure 6 shows the same combination at its highest point. The graph shows that load and the distribution of hBN volume have a substantial impact on WVL. Furthermore, Figure 6 shows an ideal combination of a 12 N load and a 6% volume of hBN, resulting in a wear volume loss of 0.0098 mm3/m.

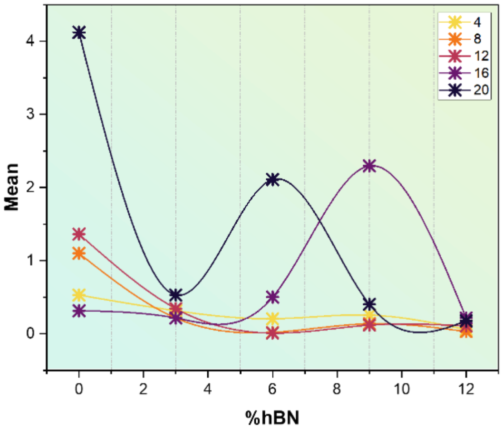

Figure 5Interaction Graph for WVL(mm³/m) [Source: Author]

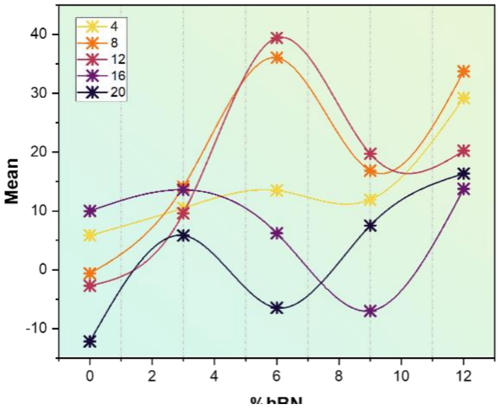

Figure 6S/N Ratio Interaction Graph for WVL[Source: Author]

4. Conclusions

This research underscores the critical need for effective substitutes in rebuilding injured joints, particularly for arthritis patients. Aseptic loosening, a significant challenge in artificial joints, is addressed by focusing on minimizing Wear Volume Loss (WVL) through bio-tribology research. Silicon nitride (Si3N4) emerges as a promising ceramic material for hip and knee replacements, and the addition of Hexagonal Boron Nitride (hBN) enhances its wear performance. DoE-Taguchi-informed experimental findings guide a mathematical model. DA-BWO refines this model to find optimum parameters: 10.632% hBN volume and 9.75 N Force minimise Si3N4wear volume loss against Alumina (Al2O3). These discoveries improve joint lifespan and resolve joint replacement therapy problems. The study's concentration on Si3N4wear volume loss against Alumina (Al2O3) counterface may restrict conclusions to other materials and counterface combinations. Investigating the combined effects of multiple parameters, such as surface finish, lubrication, and implant design, could provide a more holistic approach to joint replacement optimization.

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