E-ISSN:2583-2468

Research Article

Taguchi Method

Applied Science and Engineering Journal for Advanced Research

2025 Volume 4 Number 3 May

Publisher

Singh Publication

www.singhpublication.com

Comparative Analysis of Experimental -Based Wear Rate Investigation of Different Coatings on Nitrided AISI H13 Tool Steel

Patharkar US[1*], Patil SA[2]

DOI:10.5281/zenodo.15782893

[1*] Umesh Subhash Patharkar, Research Scholar, Department of Mechanical Engineering, Government College of Engineering, Aurangabad, Maharashtra, India.

[2] Sunil Apparao Patil, Assosiate Professor, Department of Mechanical Engineering, Government College of Engineering, Jalgaon, Maharashtra, India.

The research investigates the tribological behavior of Titanium Carbide (TiC) and Chromium Nitride (CrN) and Aluminum Titanium Nitride (AlTiN) coatings used on gas-nitrided AISI H13 tool steel when operating under multiple conditions. The Taguchi L9 orthogonal design evaluated how coating type together with temperature (40–50 °C) and load (5–15 N) affect wear rate measurements. A tribometer tester performed the wear tests and were determined by applying the circular segment method to assess the cross-sectional area of the tracks formed during testing.. The multiple linear regression prediction model for wear rate performance exhibited an error margin of less than 10% throughout every experimental trial. The statistical results from analysis of variance (ANOVA) showed coating type to be the main contributor to wear variation (p = 0.002). Within the set of tested coatings AlTiN established the highest degree of wear resistance during optimized conditions. The verification tests confirmed the accurate forecasting capabilities of the predictive model for regression while showing that duplex surface modifications work properly. Results show that using AlTiN-coated nitrided AISI H13 steel makes it possible to deploy these tools in demanding high-temperature applications which need exceptional wear protection.

Keywords: taguchi method, analysis of variance, signal to noise (s/n) ratio, optimization, wear rate, coating type

Corresponding Author	How to Cite this Article	To Browse
Umesh Subhash Patharkar, Research Scholar, Department of Mechanical Engineering, Government College of Engineering, Aurangabad, Maharashtra, India. Email: upatharkar150@gmail.com	Patharkar US, Patil SA, Comparative Analysis of Experimental -Based Wear Rate Investigation of Different Coatings on Nitrided AISI H13 Tool Steel. Appl Sci Eng J Adv Res. 2025;4(3):32-38. Available From https://asejar.singhpublication.com/index.php/ojs/article/view/151	

Manuscript Received	Review Round 1	Review Round 2	Review Round 3	Accepted
2025-04-12	2025-04-30			2025-05-19
Conflict of Interest	**Funding**	**Ethical Approval**	**Plagiarism X-checker**	**Note**
None	Nil	Yes	2.93	

1. Introduction

The need for high-performance tool steels when used in applications such as die casting, hot forging, and extrusion has pushed for rapid advancement of surface engineering technologies [1]. AISI H13 tool steel has found its application in these areas because of its high toughness quotient, thermal fatigue strength, and high temperature strength. But during the long time usage, AISI H13 suffer from wear, oxidation and thermal fatigue problems, which reduced its performance and lifetime [2]. To address these issues, there is a great need to define surface modification techniques that enhance wear on the surface without changing the mechanical properties of the substrate [3]. Co-Stereo heat-treating that involves nitriding and coating have been proved to increase the tribological performance of tool steel. Gas nitriding promotes a formation of a diffusion layer that increases the load-bearing capacity of the substrate and PVD coatings provide enhanced properties of hardness, oxidation as well as low frictional surfaces. Among the applied coatings for such applications, TiC, CrN, and AlTiN are the most investigated coatings for their tribological properties. However, all these coatings have not been mentioned and comprehensively compared especially when used on nitrided AISI H13 under different thermo-mechanical conditions in the literature. Wear resistance is one of the prime criteria which have a direct impact on the service life, productivity and management cost of tooling items [4-9]. Although individual and nitriding effects of each coating layer and different mechanical load, and operating temperatures have been studied in previous works, statistical and modeling have not been applied; also, there is no integrated and comprehensive reference source that offers a combined and comparative study of coating type, mechanical load, and operating temperature for which this work is designed to address [10-14].

The research evaluates TiC, CrN, and AlTiN coated tribological behavior on gas-nitrided AISI H13 tool steel through a systemically designed experimental protocol. Test experiments based on Wear evaluation were performed through Pin-on-Disc tribology equipment across 40°C to 50°C temperature ranges and 5 N to 15 N force capacities. The Taguchi L9 orthogonal array functioned to identify how coating type and load force and temperature values affect the wear rate. A multiple linear regression analysis was established to predict experimental parameters that affect wear rate while ensuring the prediction error remains below 10%. Confirmation experiments tested the accuracy of the developed model. This investigation has three specific research objectives which are:

[1] The evaluation aims to identify TiC, CrN or AlTiN as the most suitable coating to minimize wear under high temperature and heavy load conditions.
[2] The creation of a regression model for wear behavior prediction will focus on achieving high precision and small prediction errors.
[3] The model and optimized conditions will undergo confirmation testing for practical reliability verification.

This research creates an optimized framework to enhance AISI H13 steel surface durability through the use of duplex treatment alongside statistical optimization and predictive modeling. The research results show usefulness for tooling system sectors such as automotive, aerospace and heavy machinery manufacturing because they deliver reduced wear and longer tool service durations which bring substantial operational and economic advantages.

2. Experimentation

2.1 Methodology and Optimization Techniques

Optimization is a common technique applied to improve product designers, processes, and organizational outcomes. In the tribological systems, it was established that wear rate could be reduced through treatment in many ways. It can therefore be acknowledged that applying a number of surface engineering methods is the best since it offers statistically significant findings and conclusions. Some of the familiar approaches of optimization that are used during the process and product amplification are the Build-test-fix strategy, the Design of experiments, and the one variable at a time. In this work, wear rate is taken as a dependent variable which depends on some input variables which include coating type, applied load and temperature. Initially, the values of the stochastic parameters for the problem are determined using a preliminary OVAT analysis in order to determine the optimum range for each parameter [15-17].

Thus, the use of the Taguchi technique follows to systematically control the influencing factors. L9 orthogonal array is used in order to get maximum information form minimum number of experimental runs. The general format of orthogonal array is an L ^{k} (t) where L is the number of rows or levels and k is the number of columns or factors and t is number of symbols or strength of the orthogonal array [15-17].

OA = Ln (Xm)

X = n number of experiments,

m = number of parameters under consideration

L9 array is used to create design with three parameters in three levels which helps in optimise the experiment efficiency and data strength. Finally, in order to determining the significance of each parameter towards the overall wear behaviour, the Analysis of Variance (ANOVA) is done. The software used for the analysis of statistical data collected is the Minitab 19 that helps in making decisions on which statistician parameters to use.

2.2 Experimental Setup

Table 1 states the specification of the Tribometer setup used in this study. All the experiments were conducted Government engineering College, Aurangabad, and Maharashtra, India.

Figure 1: Tribometer Setup

Table 1: Specifications of LTR Setup

Make Model	Ducom Ltd., Banglore, India
Upper Specification	Pin(dia. × 1)- Φ4×15mm, Φ6×15mm, Φ8×15mm, Φ10×15mm. Pin Rectangular (l×b×h)-4×6×15 Pin Square (l×b×h)- 4×4×15mm, 6×6×15mm, 8×8×15mm. Ball- Φ10mm
Lower Specification	Rectangular Block (l×b×h)- 40×40×5, 30×30×5, 20×20×5mm
Lower Specification	EN-31 Steel
Lower Specification Hardness	60 HRC
Stroke Length Range	10, 20 30 fixed.
Load Range	5 to 100 N (In step of 5N)
Temperature Range	Ambient 0oC to 200o C, Ambient 200 to 200o C (For Both Lubrication). Least count..-0.21oC, Sensor: PT-100
Frequency (Speed) Range1	1-20Hz(1200rpm) Least count: 1rpm, Sensor, Proximity Sensor
Frictional Force	0.1-100N Least Count: 0.1N, Sensor- Piezo Sensor
Wear Measurement Range	±2 mm, with least count 1 micron
Water Supply	2-5 lpm Provision inbuilt for internal connection. Connect the tap water from outside while conducting heating test.
Power	230 V× 1 Φ×50Hz,8A(For Tester)

2.3 Substrate Preparation and Coating

AISI H13 tool steel samples measuring 20 mm × 20 mm × 5 mm originated from commercial material. Industrial surface engineering studies needed materials with high hot hardness and thermal fatigue resistance so the researchers selected this material.

The substrate material used in this research was rectangular samples of AISI H13 tool steel because of its suitability in high temperature service industries. Nitriding gas was conducted at process parameters which included 400 ^{0}C temperature for 24 hours in order to achieve a hardness diffusion layer on the substrate so that it can overcome load carrying capacity. After nitriding was done in the samples, 3 types of hard coatings namely Titanium Carbide (TiC), Chromium Nitride (CrN) and Aluminum Titanium Nitride (AlTiN were coated on the surface.

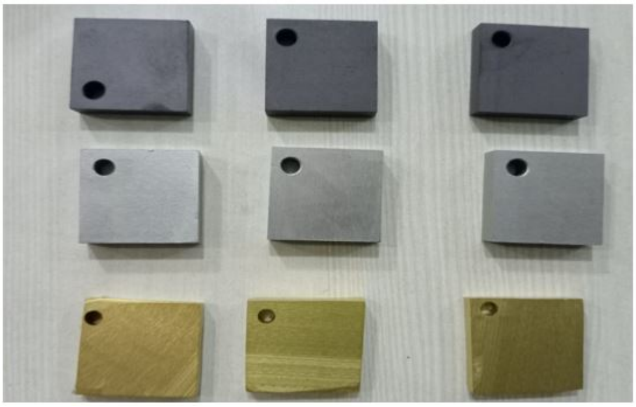

Figure 2: Coated Samples

3. Results and Discussion

In order to analyze the effect of input parameters-temperature, load and coating type on wear, efficient statistical software was used in the current research study. Further, the wear rate was fitted, and ANOVA analysis was carried out to determine the influence of each parameter on the wear rate. To predict wear rate values efficiently a multiple linear regression model was also constructed.

3.1 Experimental Result

Table 1 presents the L9 orthogonal array, detailing the wear rate measurements for experiments one through nine. Additionally, it includes the signal-to-noise (S/N) ratios corresponding to each experiment.

The S/N ratio values were calculated using Minitab 19 software. It is observed that the variation in S/N ratios is minimal across all experiments.

The **Signal-to-Noise (S/N) ratio** is a measure used in quality control and optimization processes, particularly in experiments like those using the Taguchi method. It quantifies the variation in a response (signal) relative to the unwanted variation (noise), helping to identify the most optimal settings for a given process.

Table 2: L9 orthogonal array with response characteristic

Experiments	Inputs Factors			Output Responses	
Trial No.	Coating Type	Temperature (°C)	Load (N)	Wear Rate (mm³/N·m)	S/N Ratio
1	CrN	40	5	0.0748	22.5220
2	CrN	45	10	0.0776	22.2028
3	CrN	50	15	0.0811	21.8196
4	AlTiN	40	10	0.0665	23.5436
5	AlTiN	45	15	0.0719	22.8654
6	AlTiN	50	5	0.0669	23.4915
7	TiC	40	15	0.0801	21.9273
8	TiC	45	5	0.0784	22.1137
9	TiC	50	10	0.0788	22.0695

3.2 Main Effects of Wear Rate

Optimal conditions for the characterization of superior performance were determined using the signal to noise analysis conducted in Minitab 19 software package. The parameters for the whole S/N ratio experiments including the 1st test were scrutinized carefully. By analyzing the findings of Graph 1 the highest response graph values were observed at the optimal wear rate.

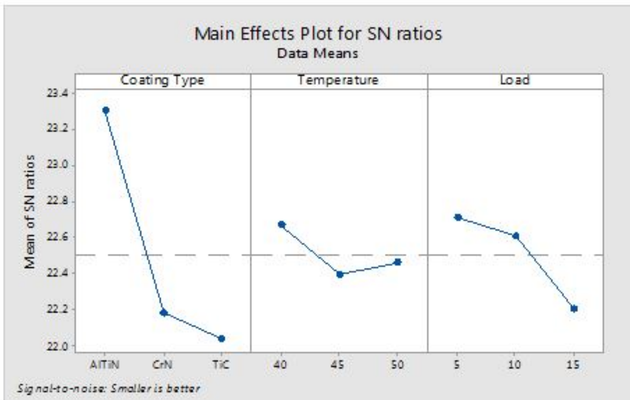

Figure 3: Main Effects Plot for S/N Ratio

The analysis identified the optimal input parameters as follows: AlTiN (level 2), Temperature 40°C (level 1), and a Load 5N (level 1). The wear rate can be seen to be affected much by control factors as can be seen in the graph above. The configuration under investigation that provided the largest S/N ratio was observed to yield the best quality without fluctuation.

Also, it graphically describes the direction and the magnitude of changes that effect on experimental results depending on the differences in the configuration of control factors within various levels.

These results highlight the importance of accuracy in controlling these parameters to realize the required performance parameters.

3.3 Analysis of Variance Result

Analysis of variance is commonly used experimental design widely employed to study the influence of more than one independent variable on an experimental study. They include, Fisher's ratio (F) which compares the variability arising from a specific parameter to the variability due to error. However, in order to evaluate the significance of the parameter, the calculated F value should be compared to the table of the standard F-distribution at a certain significance level (P-value). That is, if the calculated F value is greater than the critical F value, the parameter is considered to play a role in determining the response variable.

Analysis of variance (ANOVA) has a huge importance in determining the significance of models employed in assessing and predicting planned experiments that involve various variables. Fisher test (F test) is employed to analyze the variances in experimental data and also to use the null hypothesis to develop a systematic method of testing the null hypothesis–). The results from the

Table 3: ANOVA Result.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Coating Type	2	2.86842	1.43421	532.39	0.002	83.88
Temperature	2	0.11913	0.05957	22.11	0.043	3.48
Load	2	0.42664	0.21332	79.19	0.012	12.47
Residual Error	2	0.00539	0.00269			
Total	8	3.41958				

ANOVA table are presented showing the significance of each parameter as follows;

In the present analysis the findings of the ANOVA highlighted that all three parameters was significant coating type, load, and load had a p-value less than 0.05. This shows that these parameters effectively have a statistical significance on the bronze material. Furthermore, the total ANOVA table obtained offered the percentage breakdown of each of the factors to the total variance, which indicates the extent of the effect that each of the parameters tested exerts in the case of the experimental results. That is why, these insights confirm the appropriateness of using ANOVA to detect such factors and their significance within the context of the experiment.

Coating type (83.88%), Load (12.47%), and Temperature (3.48%) significantly affect the wear rate. Among these, Coating type has the highest contribution at 83.88%, making it the most influential parameter, while Frequency has the least impact.

3.4 Development of Regression Model for Wear Rate

The regression equation is the analysis derived from the above studied parameters and the we are using the regression equation for finding the wear rates at different level of the experimental parameters. From this equation, the predicted values of wear rates were determined so as to give a much closer look to the experimentally obtained results.

The findings of this research are presented graphically and the plots show that the wear rate data has been predicted accurately by the chosen regression model. This alignment points to robust predictability of the regression equation in capturing the performance and more specifically wear rate under different experimental parameters of inputs.

Regression Equation

Wear Rate	=	0.0627 + 0.000180 Temperature + 0.000433 Load

Table 3 compares the experimentally measured material removal rates with the values predicted using the developed mathematical model.

Table 4: Experimental and Predicted Values of Wear rate

Sr. No.	Experimental value	Predicted value	Error %
1	0.0748	0.0719	4.03%
2	0.0776	0.0751	3.26%
3	0.0811	0.0782	3.73%
4	0.0665	0.0732	9.15%
5	0.0719	0.0773	7.01%
6	0.0669	0.0739	9.43%
7	0.0801	0.0764	4.90%
8	0.0784	0.0729	7.56%
9	0.0788	0.0760	3.68%

Comparing between the regression equation wear rate to the experimental values, the difference is within 10% for each experiment and therefore asserting the accuracy of the developed regression model.

Table 5: Model Summary

S	R-Sq	R-Sq(adj)
0.0004	99.86%	99.45%

3.5 Confirmation Experiment Result

Table 4 presents the difference between the wear rate obtained from the confirmation experiment and the value predicted by the developed regression model.

Table 6: Confirmation Experiment Result

Parameter	Predicted value	Experimental value	Error %
Wear rate	0.07206	0.0659	8.54

To compare the results of the Taguchi method with the real conditions, a confirmation experiment was finally conducted at the optimal levels of parameters determined by the former, and the wear rate obtained was compared with that estimated by the regression model when the parameter levels were the same. The percent error of the experimental values with respect to the predicted values was found to be only 8.54%, proving high reliability.

4. Conclusions

This research systematically investigated the tribological behaviors of TiC, CrN, and AlTiN coatings deposited on the gas-nitrided AISI H13 tool steel. The key findings from the analysis are as follows:

Optimal Solution for Wear Rate: The optimal combination of wear parameters to achieve the best wear rate was found to be Coating type is AlTiN (Level 2), Load 5N (Level 1), and 40°C Temperature (Level 1).

[1] ANOVA Results: Analysis of Variance (ANOVA) reveals that the coating typepercentage plays the most prominent role in determining the wear rate. The contributions of each factor to the wear rate are as follows: Coating type: 83.88%, Frequency: 12.47%, and Temperature: 3.48%.
[2] From the obtained ANOVA results, it can be more effortlessly deduced that Temperature has the least effect on wear rate as compared to Coating type and Load. Out of these, the Coating typewas rated as having the most effect on wear rate.
[3] Confirmation Experiment Results: The confirmation experiment showed that the wear rate obtained under the optimal parameter combination was lower, confirming the effectiveness of the suggested parameter levels. This demonstrates that high-quality can be achieved by applying the optimal levels identified through the Taguchi method.
[4] The wear rate values from the regression model were also very accurate and exhibited prediction errors less than 10% with the actual experimentation data. This supports the regression model and proves its efficiency in wear rate prediction when all of the selected operating parameters are within the observed levels.

References

1. Ning, Dongdong, Ao Zhang, & Hui Wu. (2019). Enhanced wear performance of cu-carbon nanotubes composite coatings prepared by jet electrodeposition. *Materials*. https://doi.org/10.3390/ma12030392.

2. Patil, Amit, Ganesh Walunj, Furkan Özdemir, Rajeev Gupta, & Tushar Borkar. (2021). Tribological behavior of carbon-based nanomaterial-reinforced nickel metal matrix composites. *Materials*. https://doi.org/10.3390/ma14133536.

3. Prabhu, T. Ram, V.K. Varma, & Srikanth Vedantam. (2014). Tribological and mechanical behavior of multilayer Cu/SiC + Gr hybrid composites for brake friction material applications. *Wear. Elsevier BV*. https://doi.org/10.1016/j.wear.2014.06.006.

4. Raghuram, Harsha, Christian Katsich, K. Pichelbauer, Kurt Koschatzky, Carsten Gachot, & Ulrike Cihak-Bayr. (2019). Design of wear and corrosion resistant FeNi-graphite composites by laser cladding. *Surface and Coatings Technology. Elsevier BV*. https://doi.org/10.1016/j.surfcoat.2019.124897.

5. Stalin, B., M. Ravichandran, Alagar Karthick, M. Meignanamoorthy, G.T. Sudha, S. Karunakaran, & Bharani Murugesan. (2021). Investigations on microstructure, mechanical, thermal, and tribological behavior of Cu-MWCNT composites processed by powder metallurgy. *Journal of Nanomaterials*. https://doi.org/10.1155/2021/3913601.

6. Sun, Xun, Rui-Fen Guo, Alateng Shaga, Zhijie Hu, Ping Shen, Zhiqiang Zhang, & Qi-Chuan Jiang. (2020). Preparation and characterization of high damage-tolerance nacre-inspired magnesium alloy matrix composites with high carbon nanotube contents. *Carbon. Elsevier BV*. https://doi.org/10.1016/j.carbon.2020.02.072.

7. Mrs. Jayshri Pawar, Dr. Ravindra R. Malagi, Dr. Manoj Jadhav, & Dr. Sushant Patil. (2024). Natural fiber thermoplastic composites for mechanical and biodegradability properties.*AJBR, 27*(3S), 5241–5247. doi:10.53555/AJBR.v27i3S.3306.

8. Sushant M. Patil, Dr. R. R. Malagi, & R. G. Desavale. (2023). Investigation of vibration levels of antifriction bearing with right-angled faults on inner race and rolling element under diverse load conditions. *AIP Conf. Proc., 2716*, 030014. https://doi.org/10.1063/5.0129979.

9. Suyash A. Jangam, Aniket A. Patil, & Sushant M. Patil. 92021). Modeling and development of multi-arm robot using CATIA for pick and place operation to adapt ease in work. *International Research Journal of Engineering and Technology (IRJET), 08*(05), 2822-2827. https://shorturl.at/8OZs3.

10. I.M. Jamadar, S.M. Patil, S.S. Chavan, G.B. Pawar, & G.N. Rakate. (2013). Thickness optimization of inclined pressure vessele using non linear finite element analysis using design by analysis approach. *International Journal of Mechanical Engineering and Technology (IJMET), 3*(3), 682-689.

11. Sushant Mohan Patil. (2022). *Studies on the non-linear dynamic modelling of antifriction bearings for fault diagnosis*. http://hdl.handle.net/10603/543017.

12. Fang, B.Z. et al. (2022). Upgrading the state-of-the-art electrocatalysts for proton exchange membrane fuel cell applications. *Adv. Mater. Interfaces, 9*, 2200349.

13. Zhao, M.M. et al. (2022). Constructing porous nanosphere structure current collector by nitriding for lithium metal batteries. *J. Energy Storage, 47*, 103665.

14. Arabczyk, W. et al. (2022). Oscillatory mechanism of α-Fe (N)↔ γ′-Fe_4N phase transformations during nanocrystalline iron nitriding. *Materials, 15*, 1006.

15. Sun, J.Q. et al. (2022). In situ preparation of Nano-Cu/Microalloyed gradient coating with improved antifriction properties. *Coatings, 12*, 1336.

16. Wang, Y. et al. (2022). Advances in latest application status, challenges, and future development direction of electrospinning technology in the biomedical. *J. Nanomater.*, 3791908.

17. Xu, W.C. et al. (2022). Recent advances in open-cell porous metal materials for electrocatalytic and biomedical applications. *Acta Metall. Sin., 58*, 1527–1544.

18. García Caballero, F. et al. (2022). *Encyclopedia of materials: Metals and alloys*. Amsterdam: Elsevier.

19. Sundaram, R. Meenakshi, Takeo Yamada, Kenji Hata, & A. Sekiguchi. (2017). Electrical performance of lightweight CNT-Cu composite wires impacted by surface and internal Cu spatial distribution. *Scientific Reports. Nature Portfolio*. https://doi.org/10.1038/s41598-017-09279-x.

20. Swamy, Amit, C. Shamitha, Manoj Kumar Singh, Moti Lal Rinawa, K.V. Pradeep Kumar, Sami Al Obaid, Mahadeo A. Mahadik, Saleh Alfarraj, & Mebratu Markos. (2022). Experimental investigations on the wear behaviour of eutectic Al-7075/CNT/Graphite composites manufactured by a combination of two-stage stir and squeeze casting techniques. *Journal of Nanomaterials*. https://doi.org/10.1155/2022/7995261.