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Investigation on Tribological Behavior of Heat Treated DIN115CrV3 Steel for Cutting Tool Application by Factorial and Fractional Factorial Design

Aezhisai Vallavi M S.*, Moorthy A and Mugilan T

Department of Mechanical Engineering, Government College of Technology, Coimbatore - 641 013, Tamilnadu, India

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Abstract

The manufacturing of machines relies heavily on cutting tools. All of the critical procedures in the machine industry would have to be performed with an unacceptable level of imprecision without the use of effective cutting tools. Selecting an appropriate cutting tool material allows manufacturers to decrease machining times, eliminate unnecessary processes, raise standards of surface smoothness and accuracy, and, ultimately, increase their profits. The heat treated DIN115CrV3 steel is used as a predominant cutting tool material in the industries. Predicting wear rates at various working temperatures were crucial for selecting the cutting tool material. Considering maximum wear resistance was essential in designing the cutting tool. This research attempted to identify the wear rate influence of varying parameters like hardening temperature, tempering temperature, sliding velocity, sliding distance, and load. Each parameter with three levels was selected to design the experiment using Factorial and fractional factorial designs with restrictions. The experiments were conducted as per standard test method to conduct the wear analysis in the pin-on-disc apparatus (ASTM G99) based on the L27 design matrix, and responses such as friction force and wear rate were measured. ANOVA was performed to find out the significance of the measured results. RSM, Excel solver, and Box-Cox approach were used to predict the wear rate and frictional force. The optimized wear rate and friction forces were predicted by a grey relational approach, which was verified by a confirmatory test. The result was that 200 ºC tempering temperature offers the minimum dry wear behaviour. The sliding distance contributes significantly to wear and frictional force compared with other parameters. The hardening temperature 800 ºC, tempering temperature 200 ºC, sliding Velocity 5 m/sec, sliding distance 2000m, and load 25 N are optimal parameter combinations of the dry wear process after the heat treatment obtained by GRA and confirmation. The strength and wear behaviour of cutting tool affects the quality of manufacturing process and also reduces the accuracy industrial products. Hence, the improvements in cutting tool material through optimization is the best way of improve the manufacturing process in industries.

Keywords: DIN115CrV3, dry wear, heat treatment, grey relational approach, cutting tool, Box-Cox

1. Introduction

Cutting tools that operate at high speeds have specific material requirements, including high hardness, strong wear resistance, and good thermal fatigue resistance at elevated temperatures, all of which are met by high-speed steels (HSS). High amounts of tungsten, molybdenum, vanadium, chromium, and other alloy constituents give this type of tool steel its wear- and heat-resistant, secondary hardening properties. In today's market, cemented tungsten carbide is the material of choice fo
r cutting tools since it has the properties necessary to suit the needs of manufacturers. Single coatings, multi-layered coatings, nanocomposites, and superlattices are only some of the coatings that have been applied to cutting instruments to boost their efficiency. The use of hierarchically structured coatings is a recent development in industrial production [1,2]. Over the years, ceramic tools have helped us in a variety of ways. Advanced ceramic cutting tools have been shown in studies to be capable of performing rapid and efficient machining on challenging materials. For a number of reasons, they are among the most useful machines available. However, it's important to remember that ceramic tools, like any other, have their drawbacks [3]. Despite the low cost of the raw materials, ceramic cutting tools have a number of drawbacks, including a low transverse rupture strength (TRS), low edge strength, low fracture toughness, a high propensity to chipping (both micro and macro), and a high cost to process and finish the tools [4]. The need arises to design a cutting tool with less cost, which adapts to the new soft material being produced. In particular, the investigation of aluminium and aluminium composites is high because of lightweight, non-toxic, and high thermal conductivity [5]. However, improvement in aluminium is still hot due to its strength and cost. Today’s demand for aluminium is being used in everything from home use to aerospace equipment [6]. At the same time, a suitable tool for machining a new material also needs to be considered. The research on the investigation of cutting materials is minimum compared to developing the new composite materials. HSS and Carbide based tools are only utilized for various small-scale industries even though the material is less hardened [7,8]. Replacement of traditional cutting tool materials and decreasing the problem of developing new cutting tool material is still in the research gap.

DIN 115CrV3 is one of the cold working tool steel materials. It is easily available at a low cost. It is used in many machine tool-related applications [9-12]. It was mainly used in tap drills, breaching tools, metal saws, etc. With its great hardness and wear resistance, as well as its ease of machining,

*E-mail address: vallavims@gct.ac.in
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stainless steel is a popular material in general engineering applications. Carbon steel has low hot hardness because its hardness and wear resistance drastically decrease at operating temperatures above 200 degrees. Research is ongoing on utilizing it as a cutting tool. Thus, it is possible to create a high wear resistance cutting tool with superior properties at a low cost that can be used instead of a practical HSS cutting tool. This change can be reduced tool-based costs from 50-62.5% compared to traditional HSS costs. Before this, research was done on DIN 115CrV3 by various coating and used as a cutting tool [13]. However, the effect of tool steel over aluminium has been investigated, but its usage has been limited because of a few limitations [14-18]. With its great hardness and wear resistance, as well as its ease of machining, stainless steel is a popular material in general engineering applications. Carbon steel has low hot hardness because its hardness and wear resistance drastically decrease at operating temperatures above 200 degrees. The amount of force exerted by friction is dependent on both the load and the sliding speed. When the load is raised, the wear rate rises dramatically. On the other hand, the wear rate is decreased by increasing the sliding speed, the loading, and the sliding distance.

To replace the conventional cutting tool material with DIN115CrV3 steel, an investigation needs to be carried out on its tribological character, especially dry wear. DIN 115CrV3 material dry wear property still not investigated well with varying hardening and tempering temperature. This investigation is needed to determine how DIN115CrV3 holds its tribological properties and to analyze the optimum parameters. Wear resistance is affected by sliding velocity, track diameter, load, sliding distance, etc. [19-21]. Thus, factors influence the wear rate of different natures for different materials. Investigating those factors is essential before utilizing any material in the rubbing area. The 27 experiments were carried out by varying the input parameter levels and generating factorial and fractional factorial designs based on the model with two interactions [22-24]. With the generated experimental sequence, its frictional force and wear rate variation is measured. Also, the ANOVA test was performed to determine whether the measured results were significant. The experiment reading is investigated by single response-based minimization approach by RSM, Excel solver, Box-Cox approach and through which identify the best-fitted model by comparing the error produced. After that combined effect of response was determined by multi-response-based optimization, which was done by Grey Relational Analysis (GRA). The objective of the present research work is to investigate the influence of the wear parameters on cutting tool with regards of heat treatment. Also, to optimize the cutting parameters within the selected range of the input parameters with different single and multiple objective function-based optimization approaches.

2. Materials and experimental methodology

DIN 115CrV3 specimen was first subjected to Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Analysis (EDX) test to study its topography and confirm its composition with EDX spectrum, as shown in Figure 1.

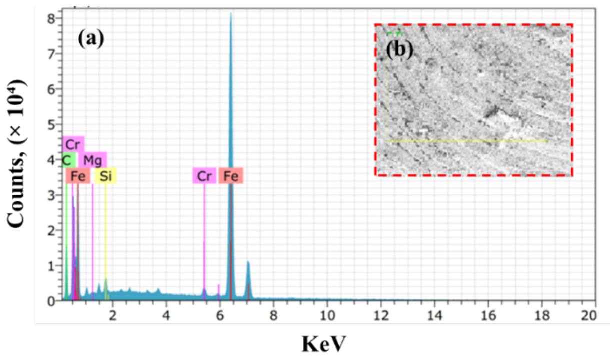

Fig. 1. (a) EDX spectrum and (b) Investigated region.

Table 1 shows the influence of the constituent and its fraction of occupation mentioned. Generally, various wear-testers were used to identify the wear: pin-on-disk (PoD) based tester, abrasive based tester, and rolling sliding-based tester. The wear test was conducted in this investigation using a computer-assisted PoD wear tester. For wear identification, cylindrical specimens were prepared for a dimension (in mm) of height: diameter to be 30:10. Workpiece materials were cut by desired size and which was allowed in shot peening operation for cleaning the dust and foreign slurries presented over in its surface. After that, the materials were kept in air-tight closer to protect from corrosion.

Table 1. The chemical compositions of the specimen.

Chemical composition %					Density (Kg/dm3)	Thermal Expansion m/(mK)	Thermal Conductivity (W/mK)
C	Cr	Si	Mg	Fe			
0.431	0.006	0.0114	0.0048	Balanced	7.80	10^{-6}	32

Multiple response-based effects could be investigated at a time by providing the sequence of steps for conducting the experiments called the design of experiments (DoE). DoE demanded a definite level and mixture of process constraints to expose the results. DoE had trivial vital points, namely planning, conducting, and analysis [25, 26]. This investigation mainly analyzed the following responses: wear rate (W_R) and frictional force (F_f). The heat treatment had a crucial role in affecting the wear pattern of materials. The hardening and tempering temperature also had taken as two additional factors. The main motive was to know the relation between the expected loads, sliding velocity of the pin, and sliding distance of the pin and how it reacted. Factorial and fractional factorial designs with randomization restrictions had been implemented [27-29], and hardening and tempering temperatures were assumed as attributes. Hence multi-factor design with a 4-point fit was used to design the experiment to identify the relation of the combination of any two factors among the three (normal loads, sliding velocity of pin, and sliding distance of pin), which was focused and were neglected the effect of hardening and tempering temperature over other interactions. The 2FI Based model was designed by Design expert 13 software with five factors, 3 level designs, as mentioned in Table 2, and L27 trials were formulated.

Table 2. Factors and levels associated with responses (wear rate and friction force).

Factor	Levels		
	Minimum	**Intermediate**	**Maximum**
Hardening temperature(°C)-T_{Hard}	780	800	820
Tempering temperature(°C)-T_{Temp}	180	200	220
Sliding Velocity (m/sec)-V_S	3	4	5
Normal load (N)-W_N	10	25	40
Sliding Distance(m)-D_S	1000	2000	3000

2.1 Heat treatment on DIN115CrV3

The hardening was done for a corresponding temperature with a holding time of 30 minutes at the vacuum furnace using brine solution as a quenching medium [37]. The properties of the quenching medium were tested, and it has been listed in Table 3. After the hardening, the material was processed for tempering at various temperatures for 30 minutes. The temperature medium was used as fresh air with a suitable incubator. The heat treatment was carried out with the help of an alumina crucible, as shown in figure 2 (a and b), with a proper lid that kept the process so efficient.

2.2 Hardness Test after heat treated DIN115CrV3

Rockwell hardness test was utilized to identify the resistance to indentation of DIN 115CrV3 as per ASTM E-18 [30]. The results of the hardness test carried out on the heat treated DIN115CrV3 were noted in Table 4. The hardness values obtained for the heat-treated DIN115CrV3 reveal that increasing hardening temperature increases the hardness value. Still, for the constant hardening temperature, the hardness increases and then decreases while tempering temperature increases [17].

Fig. 2. (a) Tempering setup, (b) Alumina Crucible with the specimen and lid.

Table 3. Property of Brine Solution (in mg/l).

pH	Chlorides	Sulphates	Hardness	Acidity	Alkalinity	TDS
6.53	358.32	453.2	546	290	70	530

Table 4. The hardness of the heat treated DIN115CrV3.

S.No	T_{Hard} (°C)	T_{Temp} (°C)	Hardness -1	Hardness-2	Hardness-3	Mean Hardness (HRC)
1.	780	180	40.8	41.1	41.1	41.00
2.	780	200	45.2	45.3	45.4	45.30
3.	780	220	36.7	36.5	36.8	36.67
4.	800	180	52.4	52.2	52.7	52.43
5.	800	200	56.9	57.3	57.1	57.10
6.	800	220	55.1	55.4	55.3	55.27
7.	820	180	52.6	52.9	52.5	52.67
8.	820	200	58.4	58.7	58.4	58.50
9.	820	220	51.7	51.5	51.8	51.67

2.3 Wear performance analysis

The pin-on-disc wear test is used to quantify wear and friction during sliding, rather than in a single direction as is the case with the unidirectional sliding wear test. Many rubbing components undergo periodic reversals in the direction of relative sliding as part of their regular operation, and this test method is meant to mimic that geometry and those motions. The information gleaned from such motion may be different from that gleaned from the identical materials' experiences with unidirectional sliding. Further, unlike material pairings, the wear may vary in speed based on the nature of the pin and the flat plate. Figure 3 shows the pin-on-plate tribo-experimental tester's setup and data collecting system.

3.Result and Discussion

Initially, the disk was cleaned with Acetone (Make: sd fine chemical ltd, Mumbai) which removed the unwanted foreign particles and debris from the previous test [31]. This investigation followed the ASTM G99-05 for the experiment the wear tests, the PoD surfaces were polished before every test, and it was done by silicon carbide sheets of 240, 320, 400,600 grit sheets [26]. Based on the hardness test, Hardened die steel (63 HRC) was used as the disc against which the sliding. The trial was tested in triplicate, and which mean value was taken into consideration. Track diameter was controlled constant, and it was maintained as 120 mm. The setup was connected with automated wear sensing for multiple data points every second and plotted wear versus time graph, through which wear rates were identified

3.1. Effect of process parameters on the wear rate

From the experiment, when the load increased to 40 N, it produced frictional heat gradually. The frictional heat generated at the contact surface lessens the strength of the material. It increased the wear rate by decreasing wear resistance. At the same time, the load was also crucial because it created high stresses at peaks and valleys of the surface finish, resulting in higher wear rates. Sliding velocity increased the separation of two surfaces and decreased the contact area.

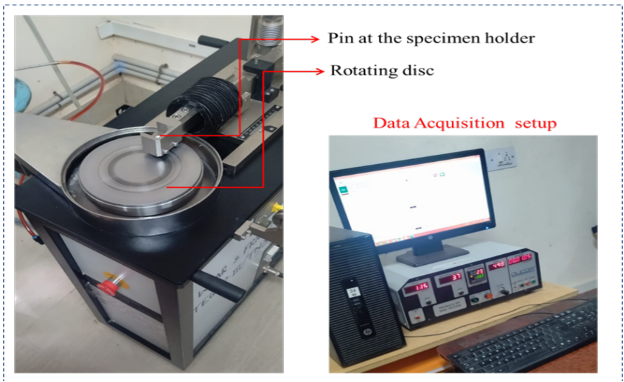

Fig. 3. Pin-on-disc apparatus and data acquisition setup.

Hence the wear rate reduces drastically when the sliding velocity increases. The heat generation grew the sliding distance increments in the pin tip which collapses the internal structure. At the same time, adhesion had dominated by increasing the cohesion activity. Due to this, the roughness was upsurge. Hence wear rate increased with the increase of sliding distance. Hardening temperature increased the hardness of the surface layer by layer, which gave the resistance to pin action.

Consequently, the hardening temperature decreased the wear rate when increased the hardening temperature. With the increasing tempering temperature, the hardness was reduced. At the same time, the impact toughness increased at first and then decreased sharply when the temperature was over 200 °C. Initially Wear rate rises then drops in the case of increases in the tempering temperature. Tempering temperature 180-200 ºC region wear rate increases drastically, then from 200 ºC wear pattern vary which changes is not able in slope.

3.2. Effect of Process Parameters on the Frictional force

The frictional force with load increases drastically when the load is increased to 40 N. Based on the velocity, the frictional force first drastically decreases and then decreases steadily when the velocity increases; based on the sliding distance, the frictional force decreases when the sliding distance increases the frictional force increases when the load increases. Because the load increases the heat at the contact surface and reduces the material strength by frictional effect [27]. The frictional force decreases when the velocity increases from 3 to 4 m/sec. After that, the frictional force slowly decreases when velocity is increased. When sliding distance is increased, the frictional force decreases.

Frictional force does not directly depend on velocity and load, but the change influences it in hardening and tempering temperature. Hardening temperature has less influence on the frictional force, which increases the frictional with minimal slope. In the case of tempering temperature, the frictional force decreases once after the significant temperature increment. Initial increment of tempering temperature, the frictional force is steadily increased with negligible value. The frictional force decreases after the increment of 200 ºC.

3.3. Analysis of Variance (ANOVA) analysis on heat treated DIN115CrV3

The individual output response, such as wear rate and frictional force significances, has been checked by conducting ANOVA. It has demanded to analyze of the effects of hardening temperature, tempering temperature, normal load, sliding velocity, and sliding distance on the wear rate, the frictional force of the DIN115CrV3 and identify the highest influencing parameter over the responses tested to compare the variance of input parameters with the variance of residual (error); From the ANOVA (table 6), sliding distance is the most significant which suggested by high F value for both the cases. Sliding distance and hardening temperature are desirable and significant factors, followed by tempering temperature for wear rate and for frictional force the sliding velocity are desirable factors. Detecting the significant terms of response has been checked by P values. In this investigation, the sliding distance p-value is less than 0.001, and the remaining values are higher p-values except for sliding velocity. Even though the few terms have high P-values, the model has been confirmed as significant by less P value. Sliding velocity is also of considerable significance next to the sliding distance. Hence, F values should be as high as possible meanwhile, P values must be less than 5%.

Table 6. ANOVA - Wear rate and Frictional force on heat treated DIN 115CrV3.

ANOVA – Wear rate after heat treated on DIN 115CrV3					**P value**	**Result**
Source	**Sum of Squares**	**DoF**	**Mean Square**	**F-value**		
Model	2.77	5	0.5547	45.24	< 0.0001	significant
Hardening Temperature (^0c)	0.0642	1	0.0642	5.23	0.0326	
Tempering Temperature (^0c)	0.0174	1	0.0174	1.42	0.2471	
Sliding Velocity (m/sec)	0.0095	1	0.0095	0.7788	0.3875	
Normal Load (N)	0.0040	1	0.0040	0.3246	0.5749	
Sliding Distance (m)	2.65	1	2.65	216.35	< 0.0001	
ANOVA – Frictional force after heat treated on DIN 115CrV3						
Model	343.85	5	68.77	59.42	< 0.0001	significant
Hardening Temperature (^0c)	0.1495	1	0.1495	0.1291	0.7229	
Tempering Temperature (^0c)	1.36	1	1.36	1.17	0.2908	
Sliding Velocity (m/sec)	5.11	1	5.11	4.42	0.0479	
Normal Load (N)	1.03	1	1.03	0.8940	0.3552	
Sliding Distance (m)	336.24	1	336.24	290.52	< 0.0001	

3.4. Single Response based on Prediction models

Based on the executed design, the output response data has intimated in Table 7. The experimental wear rate has been influenced by some input parameters sensed by proper mathematical model prediction. To identify the fitted model for prediction has been identified by three methods, such as the response surface method, the power transformation method, and Excel solver. RSM has identified the prediction of response based on the surface area and its involvement, done by design expert-12. Figure 4 & 5 shows the relation between the experiment value and the predicted value of the RSM model. Excel solver is the method that consumes less time to identify the prediction model by utilizing Microsoft Excel. The solver produces the result based on the objective function by adjusting the decision variable to satisfy the limits of the constraint.

Table 7. Experiment value compared with the predicted value of the different model.

E. No	Experiment		Predicted value: RSM Model		Predicted value: Box-Cox model		Predicted value: Excel Solver	
	W_R (µm/s)	F_f (N)	W_R (µm/s)	F_f (N)	W_R (µm/s)	F_f (N)	W_R (µm/s)	F_f (N)
1	0.8682	9.9	0.8853	11.22	0.8988	10.39	0.8650	11.137
2	0.1082	2.4	0.0284	2.07	0.0212	2.60	0.0447	2.098
3	0.1109	2.2	0.1456	2.49	0.1384	1.81	0.1252	2.404
4	0.9775	11.8	0.9293	11.42	0.9552	12.27	0.9455	11.443
5	0.5807	6.2	0.5649	6.71	0.5226	6.10	0.5445	6.620
6	0.5077	8.3	0.5100	7.20	0.5300	7.83	0.5263	7.226
7	0.4714	6.7	0.4477	6.29	0.5462	5.98	0.4639	6.315
8	0.0021	3	0.1896	2.69	0.0021	3.00	0.2058	2.709
9	0.9411	10.1	0.8670	10.51	0.9534	10.62	0.8832	10.531
10	0.8525	12.2	0.8516	10.55	0.8481	11.08	0.8191	10.504
11	0.3828	6	0.4323	6.34	0.3566	6.63	0.3998	6.287
12	0.501	6.7	0.4743	7.44	0.4598	6.48	0.4784	7.498
13	0.7885	13.1	0.7947	11.95	0.7579	12.61	0.7989	12.015
14	0.1197	2.3	0.0570	2.31	0.0953	1.57	0.0611	2.376
15	0.9618	12.3	0.8955	10.75	0.9145	11.05	0.8997	10.809
16	0.4921	3.7	0.4762	6.53	0.5638	5.68	0.4804	6.593
17	0.0188	2.3	0.1118	1.82	0.0494	2.79	0.0794	1.770
18	0.0312	2.3	0.0550	3.22	0.1031	3.01	0.0591	3.281
19	0.0884	8.1	0.3175	7.14	0.2139	7.79	0.3337	7.165
20	0.7728	10.6	0.7367	11.36	0.6779	11.40	0.7530	11.381
21	0.4764	6.3	0.4183	5.94	0.4541	6.77	0.4345	5.959
22	0.6385	9.1	0.7387	10.45	0.6385	9.10	0.7550	10.476
23	0.0378	2.2	-0.0010	1.72	0.0601	1.73	0.0152	1.743
24	0.6997	11.2	0.8539	11.77	0.8563	11.78	0.8335	11.687
25	0.1023	3.3	0.0154	3.34	0.0921	3.97	-0.0050	3.254
26	0.6796	8.5	0.4347	7.56	0.5331	7.24	0.4143	7.470
27	0.0156	2.6	-0.0030	2.62	-0.0150	2.11	0.0132	2.648

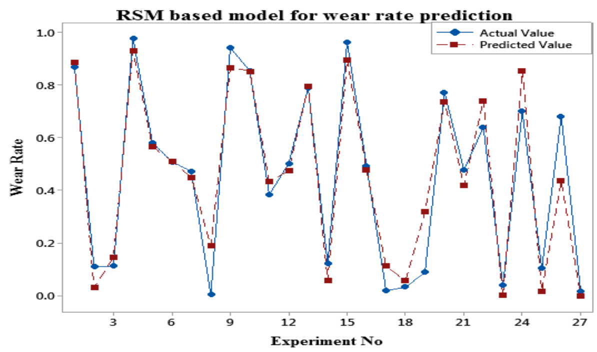

Fig. 4. RSM predicted value for wear rate.

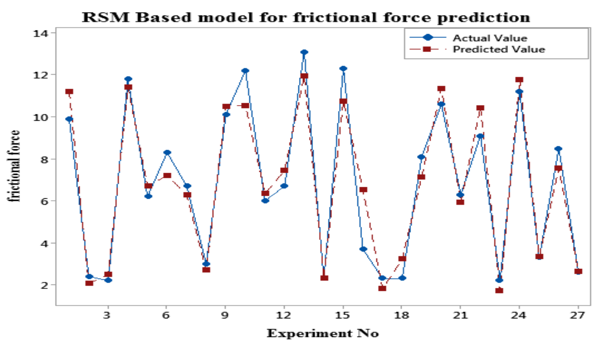

Fig. 5. RSM predicted value for the frictional force.

Power transformation is the mathematical base approach typically used to transform non-normal data into standard data. Various methods are encountered to capture the model to transform normal data, such as the Box Cox method, Johnson cure distribution, item grouping, and bootstrap method. In the Box-Cox method, Johnson distribution is widely utilized for transformation. From the experimental data, both responses followed the non-normal data, as indicated in Figures 6 and 7. The power transformation has been used to transform the data into normal and followed with the least square method to capture the prediction model by Minitab19.

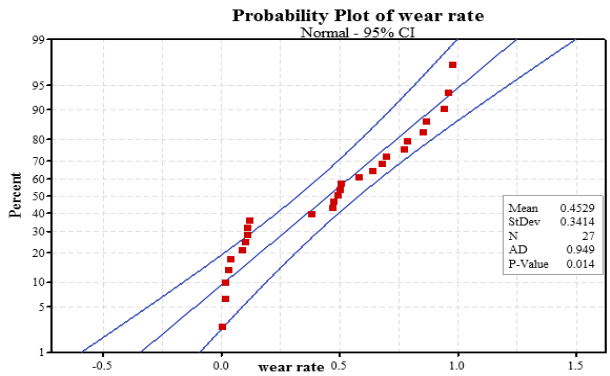

Fig. 6. Probability plot of wear rate.

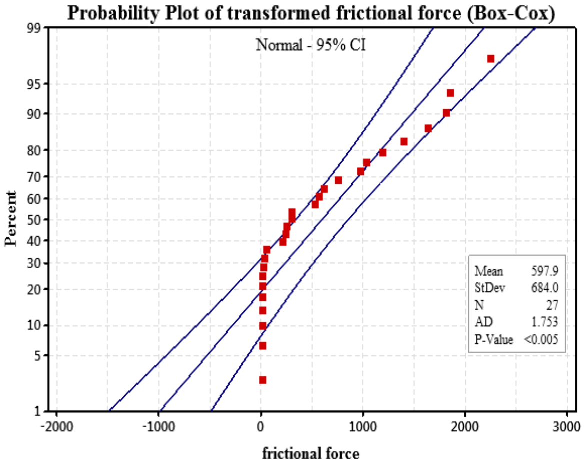

Fig. 7. Probability plot of frictional force.

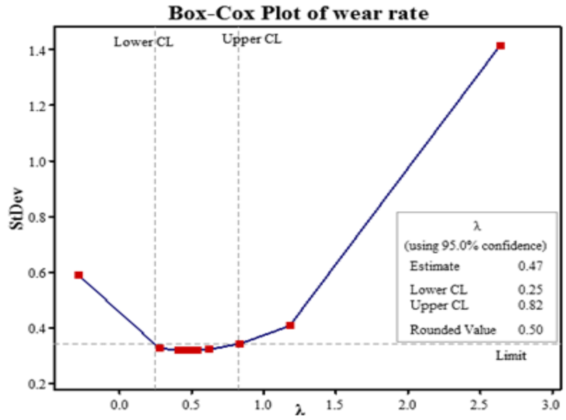

Fig. 8. Box-Cox plot of wear rate of heat treated DIN115CrV3.

The accuracy governed by the power transformer is always notable and acquired compared to others. The transformation method is reduced with improved accuracy, which is evidently proven by various research studies. Box-Cox transformation has transformed the data into normal probability with desired P-value in this investigation. The transformed data are noted in Table 8, and the Box-Cox plot for wear rate and frictional force is ploted in Figures 8 and 9. In both output responses, the rounded value of λ is 0.5, which means the transformation formula for this investigation is (output response)$^{0.5}$.

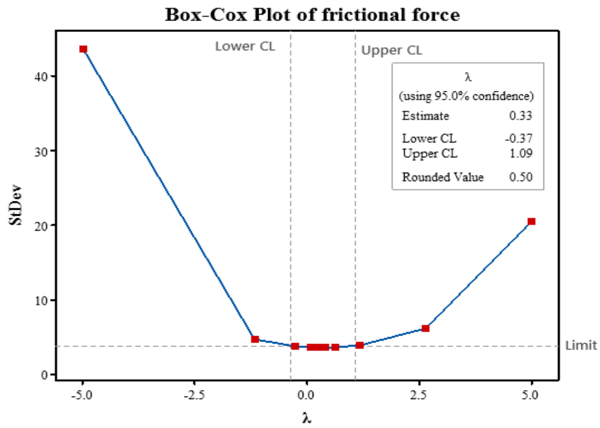

Fig. 9. Box-Cox plot of frictional force of heat treated DIN115CrV3.

Table 8. Transformed data by box Cox transformation.

E. No	W_R (µm/s)	F_f (N)	Transformed W_R (µm/s)	Transformed F_f (N)
1	0.8682	9.9	0.654424	970.299
2	0.1082	2.4	0.001267	13.824
3	0.1109	2.2	0.001364	10.648
4	0.9775	11.8	0.934007	1643.032
5	0.5807	6.2	0.195819	238.328
6	0.5077	8.3	0.130864	571.787
7	0.4714	6.7	0.104754	300.763
8	0.0021	3	9.26E-09	27
9	0.9411	10.1	0.833503	1030.301
10	0.8525	12.2	0.61956	1815.848
11	0.3828	6	0.056094	216
12	0.501	6.7	0.125752	300.763
13	0.7885	13.1	0.490236	2248.091
14	0.1197	2.3	0.001715	12.167
15	0.9618	12.3	0.889722	1860.867
16	0.4921	3.7	0.119168	50.653
17	0.0188	2.3	6.64E-06	12.167
18	0.0312	2.3	3.04E-05	12.167
19	0.0884	8.1	0.000691	531.441
20	0.7728	10.6	0.461531	1191.016
21	0.4764	6.3	0.108122	250.047
22	0.6385	9.1	0.260305	753.571
23	0.0378	2.2	5.4E-05	10.648
24	0.6997	11.2	0.342559	1404.928
25	0.1023	3.3	0.001071	35.937
26	0.6796	8.5	0.313877	614.125
27	0.0156	2.6	3.8E-06	17.576

3.5. Comparison between the models

To investigate the accuracy of the three models, each model's mean absolute error (MAE) has been identified, and its distribution is plotted in figures 10 & 11. MAE is determined by using eq. (1),

$$\% \, MAE = \left(\frac{1}{n} \sum_{i=1}^{n} \left| \frac{E_i - P_i}{E_i} \right| \right) X \quad 100\,\% \qquad (1)$$

Where, E_i is denoted by the experiment value of i[th] experiment and P_i be the predicted value of the i[th] experiment. The Box-Cox transformation has less MAE error value from the mean absolute error. Hence the Box-Cox transformation is a more accurate model for identifying the wear rate and frictional force of DIN115CrV3.

3.6. Multi response based optimization

Grey Relational Analysis (GRA) solves the inter-relationship among the numerous performing characteristics. GRA is pre-processing the data where the unit and range of any data sequence differ from others. The transformation of the results of experiments is modified between the range of 0-1. The attributes of the data sequence decide the diverse approaches of data pre-processing obtainable for the GRA [32-36]. Normalization can be calculated based on the given equations (2), (3), and (4).

For minimum is the best criterion

$$X_{ij} = \frac{max\, Y_{ij} - Y_{ij}}{max\, Y_{ij} - min Y_{ij}} \qquad (2)$$

Where,

X_{ij}- Normalized value of i[th] experiment and j[th] response

Y_{ij} - Experimentally observed value of i[th] experiment and j[th] response

maxY_{ij} - Maximum experimental observed value of j[th] response

minY_{ij} - Minimum experimental observed value of j[th] response

$$\Delta_{ij} = |X_0 - X_{ij}| \qquad (3)$$

Deviation sequence is a variation of absolute value X_0 with comparability value X_{ij} which is noted as Δ_{ij} [37]. Grey relational coefficient (GRC) is an interactive degree among the normalized and ideal experimental results calculated based on the below equation (4).

$$GRC_{ij} = \frac{\Delta_{min} + \Psi X \Delta_{max}}{\Delta_{ij} \pm \Psi X \Delta_{max}} \qquad (4)$$

Quality loss can be treated as maximum (Δ_{max}) and minimum (Δ_{min}) absolute differences and Ψ is the identification coefficient from 0 to 1. For this investigation, the impact of wear and frictional force was considered with equal effect. Hence Ψ is assumed as 50%. The mean of the GRC corresponding to each performance characteristic is calculated. Based on this, the grey relational grade is intimated [34].

GRA could be efficiently adapted for solving the complicated relationships among the selected performance characteristics. GRA was developed into a controlling tool to examine the procedures with numerous characteristics. In grey relational analysis, the intricate numerous response optimization problems could be cut down into optimization of a single response-based GRG. The larger GRG indicates the efficient correlation between performance characteristics calculated using equation (5).

$$G_i = \frac{1}{n} \sum_{j=0}^{n} GRC_{ij} \qquad (5)$$

Where n, G is the number of performance characteristics and GRC of the i[th] experiment for performance characteristics, respectively. Table 10 shows the GRC and grade for each experiment. The highest grey relational grade is the order of 1. The ANOVA for GRG is tabulate in table 11.

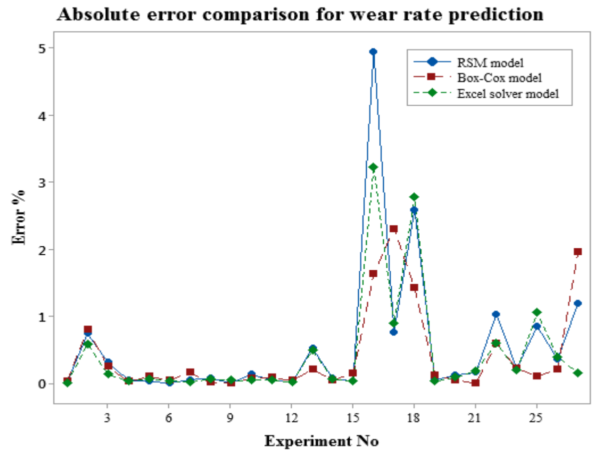

Fig. 10. Plot for absolute error comparison for various models (wear rate prediction)

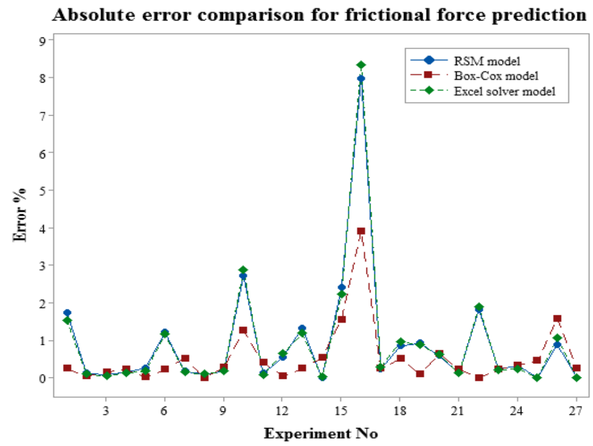

Fig. 11. Plot for absolute error comparison for various models (frictional force prediction).

Table 10. Response table -GRG on heat treated DIN115CrV3.

Level	T_{Hard}	T_{Temp}	V_S	D_S	W_N
1	0.5372	0.5828	0.5795	0.5700	0.6194
2	0.5752	0.5479	0.5564	0.5516	0.4995
3	0.5715	0.5532	0.5480	0.5623	0.5650
Delta	0.0380	0.0349	0.0315	0.0185	0.1200
Rank	2	3	4	5	1

Table 11. Grey Relational Grade- ANOVA Analyses.

Source	T_{Hard}	T_{Temp}	V_S	W_N	D_S
F Value	0.91	0.73	0.55	0.18	7.45

The hardening temperature 800 ºC, tempering temperature 200 ºC, sliding Velocity 5 m/sec, sliding distance 2000m, and load 25 N are optimal parameter combinations of the dry wear process after the heat treatment obtained by GRA and confirmation. This model has adjusted R^2 values of 89.48 % and 90.68% and predicted R^2 values of 92.31 % and 93.19 % for wear rate and frictional force, respectively. It is a convincing result because R^2 values are close to each other. The difference between the adjusted R^2 value and the predicted R^2 value is less than 3% which intimated that the number of insignificant terms is less for investigation.

4. Conclusion

The heat-treated cutting tool material was undergone the wear performance analysis using pin-on-disc apparatus. This investigation proposed the factorial and fractional factorial designs for single and multi-response-based optimization of the dry wear condition with heat treatment. Significant findings were listed as follows, From the hardness test, hardness reduced once after the 200 ºC of tempering temperature. This material behaves with good hardness for a tempering temperature of 200 ºC with quenching media brine solution. In single response optimization, Box-Cox transformation had highly fitted with less mean absolute error percentage compared with the other two models, such as excel solver and RSM. From wear test, the Hardening temperature, tempering temperature, Sliding Velocity, Load and Sliding Distance had contribution with wear rate of 2.23 %, 0.769 %, 0.28 %, 1.42 % and 95.39 %respectively and with frictional force 0.029 %, 0.23 %, 2.42 %, 0.094 % and 97.23 % respectively. In both cases, sliding distance had major contributions. From the grey relational response table, the hardening temperature 800 ºC, tempering temperature 200 ºC, sliding velocity 5m/sec, sliding distance 2000 m, and load 25 N was the optimal parameter of the dry wear condition after heat treatment. Based on the ANOVA of the GRG results, it is observed that hardening temperature, tempering temperature, sliding velocity, normal load, and sliding distance also had a significant contribution to the response after the heat treatment and their contribution values were 1.20 %, 18.38 %, 10.38 %, 44.12 %, 25.90 % respectively. Hence, the strength and wear behaviour of cutting tool affects the quality of manufacturing process and also reduces the accuracy industrial products. Hence, the improvements in cutting tool material through optimization is the best way of improve the manufacturing process in industries.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Varshney, D., Kumar, K., "Application and use of different aluminium alloys with respect to workability, strength and welding parameter optimization". *Ain Shams Engineering Journal*, 12(1), 2021, pp. 1143-1152.
2. Suwannahong, K., Wongcharee, S., Kreetachart, T., Sirilamduan, C., Rioyo, J., Wongphat, A., "Evaluation of the Microsoft Excel Solver Spreadsheet-Based Program for nonlinear expressions of adsorption Isotherm models onto magnetic nanosorbent". *Applied Sciences*, 11(16), 2021, pp. 7432.
3. Dyga, R., Witczak, S., "Investigation of effective thermal conductivity aluminum foams". *Procedia Engineering*, 42(1), 2012, pp. 1088-1099.
4. Tisza, M., Czinege, I., "Comparative study of the application of steels and aluminium in lightweight production of automotive parts". *International Journal of Lightweight Materials and Manufacture*, 1(4), 2018, pp. 229-238.
5. Swapna, D., Rao, C.S., Radhika, S., "Formability of lightweight materials-A Review". *Materials Today: Proceedings*, 18(1), 2019, pp. 426-435.
6. Garg, P., Jamwal, A., Kumar, D., Sadasivuni, K.K., Hussain, C.M., Gupta, P., "Advance research progresses in aluminium matrix composites: manufacturing & applications". *Journal of Materials Research and Technology*, 8(5), 2019, pp. 4924-4939.
7. Hedenqvist, P., Olsson, M., Wallén, P., Kassman, Å., Hogmark, S., Jacobson, S., "How TiN coatings improve the performance of high speed steel cutting tools". *Surface and Coatings Technology*, 41(2), 1990, pp. 243-256.
8. Liu, B., Qin, T., Xu, W., Jia, C., Wu, Q., Chen, M., Liu, Z., "Effect of tempering conditions on secondary hardening of carbides and retained austenite in spray-formed M42 high-speed steel". *Materials*, 12(22), 2019, pp. 3714.
9. Braun, M.T., Oswald, F.L., "Exploratory regression analysis: A tool for selecting models and determining predictor importance". *Behavior research methods*, 43(1), 2011, pp. 331-339.
10. Setia, S., Chauhan, S.R., "Comparative analysis and optimization of FEM and RSM based regression model with experimental results for the dry turning of SiCp-Al7075 composite". *Silicon*, 13(12), 2021, pp. 4681-4701.
11. Bahrami, A., Anijdan, S.M., Golozar, M., Shamanian, M., Varahram, N., "Effects of conventional heat treatment on wear resistance of AISI H13 tool steel". *Wear*, 258(5-6), 2005, pp. 846-851.
12. Behera, S.K., Meena, H., Chakraborty, S., Meikap, B., "Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal". *International Journal of Mining Science and Technology*, 28(4), 2018, pp. 621-629.
13. Öteyaka, M.Ö., Yildirim, M., Çakan, A., "On-line wear characterization of TiN-and CrN-coated DIN115CrV3 steel for cutting tools application". *Archives of Materials Science and Engineering*, 65(1), 2014, pp. 24-31.
14. Skela, B., Sedlaček, M., Kafexhiu, F., Podgornik, B., "Wear behaviour and correlations to the microstructural characteristics of heat treated hot work tool steel". *Wear*, 426(1), 2019, pp. 1118-1128.
15. Kumar, S., Bhattacharyya, A., Mondal, D.K., Biswas, K., Maity, J., "Dry sliding wear behaviour of medium carbon steel against an alumina disk". *Wear*, 270(5-6), 2011, pp. 413-421.
16. Wei, M., Wang, S., Wang, L., Cui, X., Chen, K., "Effect of tempering conditions on wear resistance in various wear mechanisms of H13 steel". *Tribology International*, 44(7-8), 2011, pp. 898-905.
17. Domitner, J., Silvayeh, Z., Sabet, A.S., Öksüz, K.I., Pelcastre, L., Hardell, J., "Characterization of wear and friction between tool steel and aluminum alloys in sheet forming at room temperature". *Journal of Manufacturing Processes*, 64(1), 2021, pp. 774-784.
18. Chai, J., Zhou, Z., Ye, C., Yao, C., Li, G., "Design and development of a novel sliding friction and wear tester with complex working conditions". *Scientific Reports*, 11(1), 2021, pp. 6903.
19. Gawande, S., Raykar, K., "Wet sliding wear behavior of EN31 rolling contact bearings for screw compressor application with statistical analysis". *Tribologia-Finnish Journal of Tribology*, 39(1− 2), 2022, pp. 39− 51-39− 51.
20. Antil, P., Saroha, A., Jakhar, C., Singh, M., Singh, R., "Optimization of wear behavior of straw combine blade through RSM and ANN models". *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 2022, pp. 1-10.
21. Sadhukhan, B., Mondal, N.K., Chattoraj, S., "Optimisation using central composite design (CCD) and the desirability function for

sorption of methylene blue from aqueous solution onto Lemna major". *Karbala International Journal of Modern Science*, 2(3), 2016, pp. 145-155.
22. Sathish, T., Karthick, S., "Wear behaviour analysis on aluminium alloy 7050 with reinforced SiC through taguchi approach". *Journal of Materials Research and Technology*, 9(3), 2020, pp. 3481-3487.
23. Sahu, T.S., George, A., Kuriachen, B., Mathew, J., Dhanish, P., "Experimental investigations on the wear behaviour of micro-EDM-fabricated textured tools during dry turning of Ti6Al4V". *Industrial Lubrication and Tribology*, 74(1), 2022, pp. 26-33.
24. Lu, Z., Du, C., Chen, Q., Niu, T., Wang, N., Song, W., "Wear and Friction Characteristics of 65Mn Steel for Spike-Tooth Harrow". *Coatings*, 11(3), 2021, pp. 319.
25. Kumar, M., Megalingam, A., "Tribological characterization of Al6061/alumina/graphite/redmud hybrid composite for brake rotor application". *Particulate Science and Technology*, 37(3), 2019, pp. 261-274.
26. Gajalakshmi, K., Senthilkumar, N., Prabu, B., "Multi-response optimization of dry sliding wear parameters of AA6026 using hybrid gray relational analysis coupled with response surface method". *Measurement and control*, 52(5-6), 2019, pp. 540-553.
27. Bingham, D., Sitter, R., Kelly, E., Moore, L., Olivas, J.D., "Factorial designs with multiple levels of randomization". *Statistica Sinica*, 2008, pp. 493-513.
28. Subramanian, K., Murugesan, S., Mohan, D.G., Tomków, J., "Study on dry sliding wear and friction behaviour of Al7068/Si3N4/BN hybrid composites". *Materials*, 14(21), 2021, pp. 6560.
29. Rajewski, J., Dobrzyńska-Inger, A., "Application of response surface methodology (RSM) for the optimization of chromium (III) synergistic extraction by supported liquid membrane". *Membranes*, 11(11), 2021, pp. 854.
30. Revankar, G.D., Shetty, R., Rao, S.S., Gaitonde, V.N., "Wear resistance enhancement of titanium alloy (Ti–6Al–4V) by ball burnishing process". *Journal of Materials Research and Technology*, 6(1), 2017, pp. 13-32.
31. Vithal, N.D., Krishna, B.B., Krishna, M.G., "Impact of dry sliding wear parameters on the wear rate of A7075 based composites reinforced with ZrB2 particulates". *Journal of Materials Research and Technology*, 14(1), 2021, pp. 174-185.
32. Hasani, H., Tabatabaei, S.A., Amiri, G., "Grey relational analysis to determine the optimum process parameters for open-end spinning yarns". *Journal of Engineered Fibers and Fabrics*, 7(2), 2012, pp. 212.
33. Girish, B., Siddesh, H., Satish, B., "Taguchi grey relational analysis for parametric optimization of severe plastic deformation process". *SN Applied Sciences*, 1(8), 2019, pp. 937.
34. Achuthamenon, S.P., Ramakrishnasamy, R., Palaniappan, G., "Taguchi grey relational analysis for multi-response optimization of wear in co-continuous composite". Materials, 11(9), 2018, pp. 1743.
35. Kobasko, N., "Investigation of transient nucleate boiling processes and their practical use in heat treating industry". *EUREKA: Physics and Engineering*, 5(1), 2017, pp. 39-48.
36. Bongale, A.M., Kumar, S., "Equal channel angular pressing of powder processed Al6061/SiC nano metal matrix composites and study of its wear properties". *Materials Research Express*, 5(3), 2018, pp. 035002.
37. Jozić, S., Bajić, D.,Celent, L., "Application of compressed cold air cooling: achieving multiple performance characteristics in end milling process". *Journal of Cleaner Production*, 100(1), 2015, pp. 325-332.