INTERNATIONAL JOURNAL OF MECHANICS
DOI: 10.46300/9104.2025.19.1 Volume 19, 2025

Determination of Best Dressing Factors in Surface Grinding Hardox 500 using MAUT Method

Vu Duc Binh[1], Nguyen Thanh Tu[2], Luu Anh Tung[2], Dinh Van Thanh[3], and Tran Quoc Hung[4,*]
[1]Viet Tri University of Industry, Vietnam
[2]Thai Nguyen University of Technology, Thai Nguyen, Vietnam
[3]East Asia University of Technology, Vietnam
[4]Ha Noi University of Industry, Thai Nguyen, Vietnam

Received: June 14, 2024. Revised: November 23, 2024. Accepted: March 9, 2025. Published: April 15, 2025.

Abstract — This study reports the findings on the use of a multi-criteria decision-making (MCDM) method to determine the optimal dressing mode for surface grinding of Hardox 500. This study investigates three objectives: surface roughness (SR), material removal rate (MRR), and wheel life (Lw). Additionally, five dressing variables were analyzed: non-feeding dressing n_n, fine dressing depth d_f, fine dressing times nf, rough dressing depth dr, and rough dressing times n_r. The Multi-Attribute Utility Theory (MAUT) method was applied to solve the MCDM problem, and the Entropy technique was used to ascertain the criterion weights. Furthermore, 16 experimental runs were designed and conducted using the L16 (4^4 x 2^1) design type. The issue regarding MCDM has been assessed. The investigation's findings indicate that option No. 7, defined by the input parameters d_r = 0.02 (mm), n_r = 3, d_f = 0.05 (mm), n_f = 3, and n_n = 0, represents the optimal dressing mode.

Keywords — Surface grinding, Hardox 500, MAUT, Entropy method, Surface Roughness, Material Removal Rate, Wheel life.

I. INTRODUCTION

So far, numerous studies have been attempted to look at the grinding process. . The impact of temperature on deep grinding performance during the machining process utilizing ultrasonic vibration was investigated in [1]. Their study is conducted using both theoretical and experimental methods. The findings indicate that ultrasonic vibration aids in diminishing cutting heat during grinding. . The use of an abrasive waterjet beam for the dressing of a diamond wheel was introduced in [2]. The application of response surface methods and artificial neural networks has been compared in their work. Both aforementioned strategies were determined to be successful for the specified task. . An investigation of the mechanism underlying the formation of residual stress during grinding has been conducted in [3]. The study examined the attributes of mechanical, thermal, and thermodynamic coupling stresses. The microstructural processes and stress modeling of representative materials are also examined.

A study that investigated the impact of coolant factors on surface finish during grinding 9CrSi tool steel was presented in [4]. Thirteen tests utilizing central composite design and response surface methodology examine the coolant's concentration and flow rate. The influence of process factors and ideal values of them to achieve the least surface roughness have been proposed. The author in [5] implemented an examination into the impact of wear tools on cutting forces, analyzing the surface structure of the tool to develop a parameter that enables the quantification of tool wear. It was discovered that, following a brief conditioning phase, cutting forces rise roughly linearly with the machined length. In the second phase, the force ratio approaches a stable value, and the primary wear mechanism is the development of smooth edges on the diamond particles. . A model for the force and temperature associated with a single abrasive in the grinding process was proposed in [6]. The study examined the input process variables, force, and residual stress. An experiment was conducted to assess the modeling of bearing rings for aircraft processing. . A novel approach for incorporating auxiliary processes in high-speed grinding has been done in [7]. This work examines the MRR mechanism, as well as the force and temperature involved in grinding. The lubricating techniques have been studied. Furthermore, the apparatus and implements for grinding have been introduced. . A study to identify the dressing parameters necessary for attaining an optimal surface finish when processing SKD11 steel has been performed in [8]. This study examined six input process

DOI: 10.46300/9104.2025.19.1 Volume 19, 2025

elements: coarse dressing depth, quantity of coarse dressings, fine dressing depth, quantity of fine dressings, non-feeding dressing, and dressing feed velocity. Coarse dressing has the most substantial impact on Ra, comprising 88.28% of the influence. Furthermore, the discrepancy between the experimental roughness average and the anticipated value is minimal.

A model to find SR resulting from grinding was proposed in [9]. The research investigated three unique configurations of abrasive grains with a model of a single-point diamond tool. Moreover, the proposed SR model was empirically validated. . Amodel to examine the influence of grinding conditions on the waviness of tooth surfaces has been established in [10]. The model accounts for the variation in spatiotemporal characteristics in continuous generating grinding, excluding factors such as system vibration and machine tool faults. . . The findings of an MCDM analysis on CBN grinding of cylindrical parts was reported in [11]. This study utilized TOPSIS, MAIRCA, and EAMR methods to address the MCDM problem, while the MEREC and Entropy techniques were implemented to determine the criteria weights. The optimal input parameters for achieving low SR and maximal MRR have been identified.

A novel model for forecasting surface roughness in CBN grinding was pfresented in [12]. The spatial distribution model of abrasive particle placements and the normal distribution model of abrasive grain size are combined in this model. Tests conducted to assess the formula's efficacy reveal that the difference between the actual and predicted surface roughness is less than 2.3%. . The influence of grinding parameters on the surface properties of Inconel 800 was examined in [13]. This study utilized numerous grinding wheels under distinct grinding settings. The surface topographies were examined utilizing three-dimensional profilometry, optical microscopy, and scanning electron microscopy (SEM). The grinding parameters and wheel properties greatly influence the surface texture, topographical features, residual stress, and surface morphology of the workpiece. . A new set of factors for enhancing the prediction of surface roughness in the grinding of Inconel 738 superalloy, taking into account the influences of dressing and grinding parameters has been proposed in [14]. A deep artificial neural network was employed in the study to predict roughness, utilizing a dataset comprising grinding parameters, dressing components, and cooling elements. The proposed approach can be connected with the Industrial Internet of Things to increase automated machining. . A surface prediction model to account for the stochastic characteristics of particle size and its distribution in grinding wheels was formulated in [15]. The model was constructed based on the computation of the transient trajectory of grain throughout the whole contact zone. It was additionally corroborated for surface topography, roughness, and material removal rate. The material removal process related to surface generation has been investigated through the anticipated ground surface and material removal rate across various grain-workpiece interaction conditions.

This work presents the findings of an MCDM evaluation focused on identifying the optimal dressing technique for surface grinding of Hardox 500. The MAUT method was utilized to address the MCDM, while the Entropy technique was employed to find the creation weights. The resolution of the MCDM issue utilizing three criteria (SR, MRR, and Lw) has led to the proposal of optimal dressing factors.

II. METHODOLOGY

A. MAUT Method

To implement the MAUT method it is crucial to adhere to the subsequent steps, [16]:

Step 1: Build the first decision-making matrix:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{mn} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Step 2: Create a normalized decision matrix by:

For MRR and Lw targets:

$$r_{ij}^* = \frac{r_{ij} - min(r_{ij})}{max(r_{ij}) - min(r_{ij})} \tag{2}$$

For SR target:

$$r_{ij}^* = 1 + \frac{min(r_{ij}) - r_{ij}}{max(r_{ij}) - min(r_{ij})} \tag{3}$$

Where i = 1, 2,..., m and j = 1, 2, ...,n.

Step 3: Calculate marginal utility score by:

$$u_{ij} = \frac{e^{(r_{ij})^2} - 1}{1.71} \tag{4}$$

Step 3: Find the final utility score by:

$$U_i = \sum_{j=1}^{n} u_{ij} \cdot w_j \tag{5}$$

In which i=1,...,m.

Step 4: Sort alternatives by maximizing Ui.

B. Entropy Method

In this study, the Entropy method has been applied to compute the criterion weights. This method can be used in the following steps, [17].

Step 1: Find indicator normalized values:

$$p_{ij} = \frac{x_{ij}}{m + \sum_{i=1}^{m} x_{ij}^2} \tag{6}$$

Step 2: Calculate the Entropy for objectives:

$$me_j = -\sum_{i=1}^{m}\left[p_{ij} \times ln(p_{ij})\right] - \left(1 - \sum_{i=1}^{m} p_{ij}\right) \times ln\left(1 - \sum_{i=1}^{m} p_{ij}\right) \quad (7)$$

Step 3: Determine the weight of objectives:

$$w_j = \frac{1 - me_j}{\sum_{j=1}^{m}(1 - me_j)} \quad (8)$$

III. EXPERIMENTAL WORK

An experiment has been performed to identify the optimal dressing factor for surface grinding Hardox 500. To achieve high efficiency in dressing process, this process should be divided into three steps: rough dressing, fine dressing, and non-feeding dressing. Therefore, in this experiment, five dressing factors (dr, nr, df, nf, and nn) have been investigated, [18]. Table I displays the levels of the input factors utilized in the experiment. The experiment applied an L16 (4^4x2^1) configuration, comprising 16 experimental runs, conducted with Minitab R19 software. Figure 1 illustrates the configuration of the experiment. The apparatus comprises a surface grinding machine (PSG-CL3060AH, Taiwan), a grinding wheel (Cn60MV1G V1, 350x40x127 35 (m/s)), a diamond dresser (3908-0088C type II, Russia), and a force measuring device (Kistler 9257BA, Germany). The experimental procedure was outlined as follows: All experiments were conducted in triplicate. The SJ201 model surface roughness device has been used to assess SR. The useful life of the wheel is influenced by the time taken to start grinding after dressing and the use of a standard Py spike. The wheel life and the measured total material volume were used to calculate the MRR. Table II presents the experimental matrix and the resulting findings.

Fig. 1. Configuration for the experiment

IV. DETERMINING BEST DRESSING FACTORS

To deal with the MCDM issue of identifying an ideal dressing setting, the initial determination of the creation weights is conducted using the Entropy method, as detailed in Section 2.4 below: First, finding the values of p_{ij} as outlined in formula (6). Determine the Entropy value for each indication mej using formula (7). Calculate the criterion weight w_{ij} using Equation (8). The weights of RS, MRR, and Lw have been determined to be 0.4606, 0.3056, and 0.2338, respectively.

Table I. Dressing parameters

No.	Factor	Level			
		1	2	3	4
1	d_r	0.015	0.02	0.025	0.03
2	n_r	1	2	3	4
3	d_f	0.005	0.01	-	-
4	n_f	0	1	2	3
5	n_n	0	1	2	3

Table II. Experimental matrix and output findings

No.	d_r	n_r	n_f	n_n	d_f	SR (µm)	MRR (mm^3/s)	Lw (min.)
1	0.015	1	0	0	0.005	0.67	5.73	23.07
2	0.015	2	1	1	0.005	0.59	5.71	33.20
3	0.015	3	2	2	0.010	0.59	5.51	5.05
4	0.015	4	3	3	0.010	0.65	6.43	1.90
5	0.020	1	1	2	0.010	0.44	8.49	19.90
6	0.020	2	0	3	0.010	0.48	5.22	41.20
7	0.020	3	3	0	0.005	0.62	3.36	44.00
8	0.020	4	2	1	0.005	0.79	11.77	23.73
9	0.025	1	2	3	0.005	0.45	5.64	5.23
10	0.025	2	3	2	0.005	0.81	6.53	36.67
11	0.025	3	0	1	0.010	1.22	3.97	28.03
12	0.025	4	1	0	0.010	0.87	6.01	37.27
13	0.030	1	3	1	0.010	0.94	7.40	26.47
14	0.030	2	2	0	0.010	0.69	6.65	35.17
15	0.030	3	1	3	0.005	1.38	5.60	41.77
16	0.030	4	0	2	0.005	0.77	11.10	16.97

Section 2.1 outlines the implementation of the MAUT technique. Following the computation of the decision-making matrices via Equation (1), the normalized decision matrix was produced by applying Equations (2) and (3). The marginal utility score is then calculated by (4). The ultimate utility score was then calculated using Equation (5). The options were ranked through the optimization of the user interface. Table III displays the calculated parameters and the corresponding rankings of options obtained from this method. Table III indicates that option 2 is optimal, demonstrating the highest Ui value (Ui=0.7906).

Figure 2 presents the option's ranking obtained through the application of the MAUT technique, as informed by the data in Table III. The analysis demonstrates that option 7 is the optimal choice. The optimal dressing parameters, as indicated by the results and Table II, are: d_r = 0.02 (mm), n_r = 3 (times), d_f = 0.005 (mm), n_f = 3 (times), and n_n = 0.

Table III. Computed findings and option's ranking by MAUT

Trial	r_{ij}*			u_{ij}			Ui	Rank
	Ra	MRR	Tw	Ra	MRR	Tw		
1	0.7489	0.7178	0.5029	0.4399	0.3941	0.1682	0.3624	8
2	0.8372	0.7205	0.7435	0.5938	0.3979	0.4315	0.4960	5
3	0.8333	0.7448	0.0748	0.5862	0.4335	0.0033	0.4032	6
4	0.7774	0.6348	0.0000	0.4854	0.2901	0.0000	0.3122	13
5	1.0000	0.3896	0.4276	1.0047	0.0959	0.1173	0.5195	4
6	0.9536	0.7784	0.9335	0.8669	0.4870	0.8129	0.7382	2
7	0.8087	1.0000	1.0000	0.5398	1.0047	1.0047	0.7906	1
8	0.6319	0.0000	0.5185	0.2869	0.0000	0.1804	0.1743	15
9	0.9831	0.7282	0.0791	0.9524	0.4089	0.0037	0.5645	3
10	0.6030	0.6231	0.8259	0.2564	0.2774	0.5719	0.3366	10
11	0.1772	0.9267	0.6207	0.0187	0.7955	0.2748	0.3159	12
12	0.5373	0.6851	0.8401	0.1957	0.3503	0.5996	0.3374	9
13	0.4652	0.5191	0.5836	0.1413	0.1809	0.2373	0.1758	14
14	0.7286	0.6087	0.7903	0.4095	0.2623	0.5071	0.3873	7
15	0.0000	0.7331	0.9470	0.0000	0.4161	0.8489	0.3256	11
16	0.6438	0.0797	0.3580	0.3003	0.0037	0.0799	0.1582	16

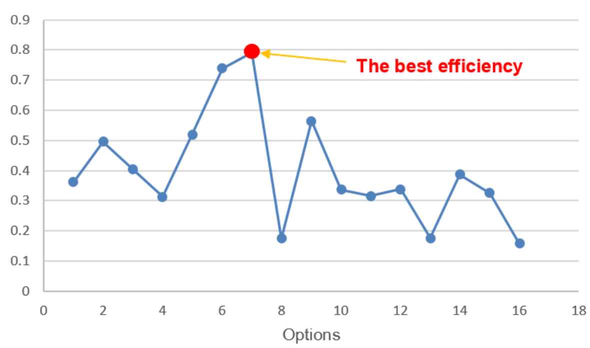

Fig. 2. Ranking of options by MAUT

V. CONCLUSIONS

This research presents the findings of an MCDM work aimed at identifying the optimal dressing strategies for the surface grinding of Hardox 500 steel. This study examines three objectives: minimizing SR, maximizing MRR, and maximizing Lw. The MAUT approach was employed to address the MCDM issue, while the Entropy technique was utilized to determine the weights of objectives. Additionally, five input parameters were analyzed: ar, nr, af, nf, and n0. The experiment employed the Taguchi technique with an L16 ($4^4 + 2^1$) design, and the results were analyzed using Minitab R19 software. The MCDM problem has been effectively addressed, and optimal input settings were found. The study's results indicate that ideal dressing factors for getting minimum SR, maximum MRR, and maximum Lw concurrently are: $d_r = 0.02$ (mm), $n_r = 3$ (times), $d_f = 0.005$ (mm), $n_f = 3$ (times), and $n_n = 0$. The findings are derived from the examination of Hardox 500 steel. Nonetheless, it may also serve as a reference in the study of material grinding.

ACKNOWLEDGMENT

This work was supported by Thai Nguyen University of Technology.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The author wrote, reviewed and edited the content as needed and they have not utilised artificial intelligence (AI) tools. The authors take full responsibility for the content of the publication.

References

[1] Biao Zhao, Xiaowei Wang, Tao Chen, Wenfeng Ding, Ning Qian, Jiuhua Xu, Simulation and experimental thermal analysis of ultrasonic vibration-assisted high-efficiency deep grinding of γ-TiAl blade tenon. Applied Thermal Engineering, Volume 258, Part A, 1 January 2025, Page 124629. https://doi.org/10.1016/j.applthermaleng.2024.124629

[2] Shibo Zhang, Zhenzhong Zhang, Hongyu Xing, Guangc hao Hao, Xiaoliang Liang, Analysis and optimization of abrasive waterjet dressing parameters for surface texturing of diamond grinding wheels. Diamond and Related Materials, Volume 149, November 2024, 111661. https://doi.org/10.1016/j.diamond.2024.111661

[3] Peng Gong, Yanbin Zhang, Chunjin Wang, Xin Cui, Ru nze Li, Shubham Sharma, Mingzheng Liu, Teng Gao, Z ongming Zhou, Xiaoming Wang, Yusuf, uleiman mbatta, Changhe Li , Residual stress generation in grinding: mechanism and modeling. Journal of Materials Processing Technology, Volume 324, March 2024, 118262. https://doi.org/10.1016/j.jmatprotec.2023.118262

[4] Le Xuan Hung, Vu Thi Lien, Vu Ngoc Pi, Banh Tien Long. A study on coolant parameters in internal grinding of 9CrSi steel. Materials Science Forum (Volume 950), Pages24-31. https://doi.org/10.4028/www.scientific.net/MSF.950.24

[5] E. Irazu, U. Alonso, B. Izquierdo, L. Godino, Grinding of C/SiC ceramic matrix composites: Influence of grinding parameters on tool wear. Wear, Volumes 558–559, 15 December 2024, 205582. https://doi.org/10.1016/j.wear.2024.205582

[6] Lai Hu, Banhu Li, Lee Heow Pueh, Zixi Wang, Yuming Wang, Effect of single/multi-particle grinding parameters on surface properties of bearing steel GCr15. Engineering Science and Technology, an International, Journal, Volum 58, October 2024.101851. https://doi.org/10.1016/j.jestch.2024.101851

[7] Yu-Long Wang, Yan-Bin Zhang, Xin Cui, Xiao-Liang Liang, Run-Ze Li, Ruo-Xin Wang, Shubham Sharma, Ming-Zheng Liu, Teng Gao, Zong-Ming Zhou, Xiao-

Ming Wang, Yusuf Suleiman Dambatta, Chang-He Li, *High-speed grinding: from mechanism to machine tool.* Advances in Manufacturing, Volum 13, pages 105-154, (2025). https://doi.org/10.1007/s40436-024-00508-x

[8] Le Xuan Hung, Tran Ngoc Giang, Quoc Hoang Tran, Nguyen Hong Linh, Dinh Ngoc Nguyen, Vu Ngoc Pi, Determining the optimum set of dressing parameters satisfying minimum surface roughness when conducting the internal grinding of hardened SKD11 steel. Solid State Phenomena, Volume 324, P 58-65.https://doi.org/10.4028/www.scientific.net/SSP.324.58.

[9] Yueming Liu [a], Andrew Warkentin [b], Robert Bauer [b], Y adong Gong , Investigation of different grain shapes and dressing to predict surface roughness in grinding using kinematic simulations. Precision Engineering, Volume 37, Issue 3, July 2013, Pages 758-764. https://doi.org/10.1016/j.precisioneng.2013.02.009.

[10] Yijie Tao, Guolong Li, Yu Wang, Hao Yu, Yu Sun, Xiaoliang Zhao, *Effect of grinding parameters on tooth surface waviness in continuous generating grinding for electric vehicle gears.* Journal of Manufacturing Processes, 2024. 115: p. 323-341. DOI: 10.1016/j.jmapro.2024.02.015.

[11] Trieu Quy Huy, Bui Thanh Hien, Tran Huu Danh, Pham Duc Lam, Nguyen Hoang Linh, Vu Van Khoa, Le Xuan Hung, Vu Ngoc Pi, Application of topsis, mairca and eamr methods for multi-criteria decision making in cubic boron nitride grinding, Eastern-European Journal of Enterprise Technologies; 3 (1(117)), 58-66; ISSN 1729-3774. DOI: 10.15587/1729-4061.2022.260093.

[12] Yanbin Zhang, Peng Gong, Lizhi Tang, Xin Cui, Dongzhou Jia, Teng Gao, Yusuf Suleiman Dambatta and Changhe Li, *Topography modeling of surface grinding based on random abrasives and performance evaluation.* Chinese Journal of Mechanical Engineering (2024) 37:93 https://doi.org/10.1186/s10033-024-01081-x.

[13] N. E. Arun Kumar, M. Ganesh, F.Antony Leo, *Study on the impact of grinding variables on surface grinding of inconel 800.* Materials and Manufacturing Processes, Volum39, 2024 – Issue 14, Pages 2069-2079. https://doi.org/10.1080/10426914.2024.2390373.

[14] Mohammadjafar Hadad, Samareh Attarsharghi, Mohsen Dehghanpour Abyaneh, Parviz Narimani, Javad Makarian, Alireza Saberi, Amir Alinaghizadeh, *Exploring New Parameters to Advance Surface Roughness Prediction in Grinding Processes for the Enhancement of Automated Machining.* Journal of Manufacturing and Materials Processing, 2024. **8**(1): p. 41. https://doi.org/10.3390/jmmp8010041.

[15] Xin Li, Xueping Zhang, Zhenqiang Yao, *Surface generation and material removal mechanism incorporated with the randomness of grain size and distribution in grinding.* Precision Engineering, 2024. 86: p. 30-47. https://doi.org/10.1016/j.precisioneng.2023.11.004.

[16] I. Emovon, R.A. Norman, A.J. Murphy, Methodology of using an integrated averaging technique and MAUT method for failure mode and effects analysis. Journal of Engineering and Technology, 2016. 7(1): p. 140-155.

[17] Hieu, T.T., N.X. Thao, and L. Thuy, Application of MOORA and COPRAS Models to Select Materials for Mushroom Cultivation. Vietnam Journal of Agricultural Sciences, 2019. 17(4): p. 32-2331.

[18] Le Xuan Hung, Optimization on determination of dressing parameters, lubricant conditions and exchanged grinding wheel diameter in internal cylindrical grinding procsess (In Vietnamese), PhD thesis, Thai Nguyen University of Technology, 2019.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Conceptualization Vu Duc Binh and Tran Quoc Hung; Methodology: Dinh Van Thanh; Software and Experiment: Luu Anh Tung and Nguyen Thanh Tu; Validation: Tran Quoc Hung; Formal analysis: Nguyen Thanh Tu; Writing: Tran Quoc Hung and Luu Anh Tung; All authors have read and agreed to the published version of the manuscript.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This work was supported by Thai Nguyen University of Technology.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.