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DETERMINING THE EFFECT OF ROLLER BURNISHING PARAMETERS ON SURFACE HARDNESS USING THE TAGUCHI METHOD

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Abstract

This research paper investigates the effect of roller burnishing parameters on the surface hardness of 20MnCr5 steel, utilizing the Taguchi method for optimization. The study encompasses a comprehensive analysis of various burnishing parameters, including burnishing speed, feed rate, depth of penetration, and the number of passes, while maintaining constant conditions of the burnishing tool and lubrication. An L18 orthogonal array was employed to efficiently design experiments that reveal the impact of each parameter on surface hardness, measured in HRB. Through statistical analysis, particularly ANOVA, it was determined that burnishing speed, condition, and number of passes significantly influence surface hardness, while feed rate and depth of penetration have a lesser effect. The optimal parameters identified for achieving maximum surface hardness were the second level of burnishing speed, condition, and feed, combined with the maximum number of passes. This research contributes valuable insights into the optimization of roller burnishing processes, highlighting its potential for enhancing the mechanical properties of metallic components in industrial applications.

Keywords *:- surface hardness,L18, roller burnishing*

1 BURNISHING

Burnishing, a captivating and intricate process, has long been a subject of fascination within the realm of material science and engineering. This review article delves into the intricacies of burnishing, examining the state-of-the-art advancements, the impact of various parameters, and the potential applications of this versatile technique. The optimisation of burnishing parameters is a crucial aspect in ensuring the desirable outcomes of the process

2 The Effect of Burnishing on Hardness

Burnishing is a surface-finishing process that involves the application of compressive forces to a metallic surface, resulting in the enhancement of its mechanical properties, particularly its hardness. This research paper aims to investigate the effect of burnishing on the hardness of various metallic materials, exploring the underlying mechanisms and factors that contribute to the observed changes.

The existing literature suggests that burnishing can significantly improve the surface hardness of metallic materials. For instance, Saldaña-Robles et al. found that the surface hardness of a material can be increased by 16% to 60% after burnishing, depending on the input parameters used in the process. (Rue et al., 2021) Similarly, a study on the burnishing of aluminium-magnesium-graphite composites revealed that the surface hardness of the metallic composites increases with the increase of the burnishing force and decreases with the increase in the burnishing feed rate and burnishing speed. (Hayajneh et al., 2015) Furthermore, the investigation on the burnishing of friction stir welded aluminium alloy components demonstrated that burnishing is an economical and feasible mechanical treatment for the quality improvement of component surfaces. (Rodríguez et al., 2019)

The microstructural and nanomechanical changes induced by burnishing have also been explored in the literature. According to a study on the evaluation of burnished subsurface mechanical behaviour using nanoindentation, the hardening film formed on the surface of the burnished specimens can be larger than 4 micrometres, and the nanohardness can be as high as 2.2-3.5 GPa, depending on the burnishing parameters and the distribution and position of the second phase particles (Rue et al., 2021) (Luo et al., 2011).

3 NEED AND SIGNIFICANCE

The literature survey reveals that a lot of research performed on burnishing of steels by altering various input parameters used and the work related to optimization and improvement in properties of steel Hitherto, no work has reported on investigating the effect of burnishing parameters on 20MnCr5steel. The 20MnCr5steel has many applications in burnished mechanical components like shafts, bushes, bearings etc. So optimization of the process parameters of 20MnCr5steel has a high potential for future research. In planned work, an effort is desired to be made for analyzing the effect of burnishing process parameters on mechanical properties of 20MnCr5steel by altering the burnishing process parameters.

Objective of study

To investigate the effect of burnishing process parameter of 20MnCr5and to optimize the burnishing process parameters in order to enhance the surface hardness.

Table 3.1 Selected input machining parameters

Variable	Set-up	Units
Work piece	20MnCr5steel	---
Work piece material size	Dia 40 length 400	Mm
Tool roller material	Carbide	---
Tool roller diameter	40	Mm
Burnishing condition	Wet-Dry	----
Burnishing Speed	100, 150, 200	Rpm
Burnishing feed	0.5, 1.0, 1.5	mm/rev
Depth of penetration	0.1, 0.2, 0.3	Mm
No. of passes	1,2,3	---

3.1 BURNISHING PROCESS PARAMETERS

3.1.1 Input Parameters

1. Burnishing speed
2. Burnishing feed
3. Depth of penetration
4. No of passes
5. Burnishing conditions (dry or with lubrication)
6. Burnishing tool (Roller or Ball)

Out of these input parameters, the parameters, burnishing speed, burnishing feed, depth of penetration and number of passes selected in the present study keeping the other parameters constant. Roller burnishing tool is being used.

3.1.2 Output Parameter

The output parameters selected for the present work are as follows

1. Surface Hardness, HRB

3.1.3Constant Parameters

1. Burnishing tool - Roller Burnisher
2. Work Piece Material - 20MnCr5 steel
3. Burnishing Condition - Wet-Dry using Standard cutting Oil

3.2 WORKPIECE MATERIAL

For the present study 20mncr5 steel is selected as work piece material having a diameter 40 mm and length of 300 mm. The chemical composition of 20MnCr5 steel is shown in Table 3.2

Table 3.2 Chemical Composition (in weight %)

Grade	Chemical composition (WT %)					
	C	**Mn**	**Si**	**P**	**S**	**Cr**
20MnCr5	0.17- 0.22	1.10--1.50	≤0.25	≤0.030	0.010-0.035	1.00- 1.30

3.4 BURNISHING TOOL

The burnishing tool selected for the present investigation is single roller burnisher which is available from the market. The roller of the burnishing tool is of carbide as shown in figure.

Figure 3.1 Burnishing tool from Bright burnishing tools Pvt. Ltd., Coimbotore

Table 3.3 Tool Specifications

Part Name	Specifications
Shank Dimensions	25 mm× 25mm
Shank Length	100 mm
Roller Material	Carbide
Roller Diameter	48 mm
Roller Width	30 mm

4. DESIGN OF EXPERIMENT (DOE)

Design of experiment (DOE) is the first step in any experimental work. Design of Experiments (DOE) is a statistical technique introduced by R.A. fisher in Englandin1920's. The objectives of the design of experiment are as follows:

1) Study the effect of multiple variables simultaneously.
2) Optimize the product and process design.
3) Study the effect of different factors on the process.
4) Study the impact of individual factor on the performance of other.
5) Determine the factor that has more influence.

DOE refers to planning, designing and analyzing an experiment so that valid and objective conclusions can bedrawn effectively and efficiently. In performing a designed experiment, changes are made to the input variables and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Each factor can take several values during the experiment. Each such value of the factor is called a level. A trialorrun is a certain combination off actor levels whose effect on the output is of interest. It is essential to incorporate statistical data analysis methods in the experimental design in order to draw statistically sound conclusions from the experiment. Also, interaction effects among different factors can be studied through designed experiments. In 1980s Taguchi devised special method which uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. This method developed rules to carry out experiments, which further simplified and standardized the design of the experiment, along with minimizing the number of factor combinations that would be required to test for the factor effects.

4.1 Taguchi Method

Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to statistical process controls which attempt to control the factors that adversely affect the quality of production. Taguchi method systematically reveals the complex cause and effect relationship between design parameter and performance. These lead to building quality performance into process and product before actual production begins. Taguchi method has rapidly attained prominence because wherever they have been applied, they lead to the significant reductions into process and products before actual production begin.

The foundation of quality depends upon two premises:

1. Society incurs a loss any time the performance of the product is not on target.

2. Product and process design require a systematic development, progressing stepwise through system design, parametric design and finally tolerance design.

The first point suggests that whenever the performance of a product deviates from its target performance, society suffer loss. Such a loss has two components: The manufacture incurs loss when he repairs or rectified return or rejected product. The second point aims at quality engineering, a discipline that aims at engineering not only function but also quality performance into products and process. The following seven points highlight the distinguish feature of Taguchi's approach which aimed at assuring quality

1. Taguchi defined the term quality as the deviation from on target performance that appears to be first paradox. According to Taguchi the quality of a manufactured product is the total loss generated by that product to the society from the time it is shipped.

2. In a competitive economy continuous improvement (CQI) and cost reduction are necessary.
3. A CQI programme includes continuous reduction in the variation of product performance characteristic in their target values.
4. Customerlossattributetotheproductperformancevariationisoftenproportionaltothe square of the deviation performance characteristic from its target value.
5. The final quality and cost of a product manufactured depends primarily on the engineering design of the product and its manufacturing process.
6. Statically planned experiments can efficiently and reliably identify the settings of the product and process parameters that reduce performance variations.

In the present research work, selected input machining parameters with their designation are listed in Table 4.1. and Table 4.2.Enlists levels of machining parameters and assigned values of machining parameters at these levels and their designation for experimental work.

Table 4.1 Input machining parameters with their designation

Burnishing Parameter	**Condition**	**Burnishing Speed(rpm)**	**Burnishing Feed(mm/rev)**	**Depth of Penetration(mm)**	**Number of Passes**
Symbol	A	B	C	D	E

The next step is to select an appropriate array keeping in mind that the total DOF for the orthogonal array should be greater than or at least equal to those for the process parameters. L_{18} (3^4 x 2^1) orthogonal array is selected for the present study. This orthogonal array has 5 columns and 18 rows. One machining parameter is assigned to each column. Total 18 rows give the parametric combination for each set of experiment.

Table 4.2 Assigned values of input machining parameters at different levels and their designation

The experimental combinations of the machining parameters using the L_{18} orthogonal array are presented in

Factor Designation	**Burnishing Parameter (units)**	**Levels and corresponding values of Machining parameter**		
		Level-1	**Level-2**	**Level-3**
A	Burnishing condition	Wet	Dry	--------
B	Burnishing speed (rpm)	100	150	200
C	feed (of mm / rev)	0.5	1.0	1.5
D	Depth of penetration (mm)	0.1	0.2	0.3
E	No. of passes	1	2	3

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Table 4.3

Table 4.3 Design Matrix of L_{18} (3^3 x 2^1) orthogonal array

Experiment No.	Burnishing condition	Burnishing Speed(rpm)	Burnishing feed (mm/rev)	Depth of Penetration(mm)	No. of passes
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	2	3
5	1	2	2	3	1
6	1	2	3	1	2
7	1	3	1	3	2
8	1	3	2	1	3
9	2	3	3	2	1
10	2	1	1	1	1
11	2	1	2	2	2
12	2	1	3	3	3
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

Burnishing of Specimen

The speed of the lathe machine is fixed by proper selection of gear train. The Centre lathe machine is now switched on. The roller of the burnishing tool is moved towards the rotating specimen. The roller also starts rotating when it comes in contact with rotating specimen. The force can be generated between tool and specimen by moving the tool towards specimen and checking the required parameters with the help of dynamometer. Now select the required feed of the tool post with the help of leaver provided on lathe machine. Put some lubricant on the specimen. Now burnishing of the specimen will starts. Stop the lathe machine after completion of burnishing on one region. So, now by change the parameters (burnishing condition, burnishing speed, burnishing feed and no of passes depth of penetration), the burnishing of region was done.

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Inspection of Parameters

Once the burnishing has been done on all the specimens then it is investigated for output parameter surface hardness (HRB) with the help of hardness tester.

5 SURFACE HARDNESS (HRB)

The experimental results for Surface hardness are tabulated in Table 5.1

Table 5.1 Experimental results for Surface Hardness (HRB)

Code given on specimen	Condition	Speed	Feed	Depth of Penetration	Number of passes	HRB			HRB
						Trail I	Trial II	Trail III	
A	WET	100	0.5	0.1	1	87	91	89	89
B	WET	100	1.0	0.2	2	90	92	88	90
C	WET	100	1.5	0.3	3	89	91	92	91
D	WET	150	0.5	0.1	2	92	93	91	92
E	WET	150	1.0	0.2	3	93	91	92	92
F	WET	150	1.5	0.3	1	91	90	87	89
G	WET	200	0.5	0.2	1	87	89	89	88
H	WET	200	1.0	0.3	2	88	88	84	87
I	WET	200	1.5	0.1	3	90	89	91	90
J	DRY	100	0.5	0.3	3	95	91	92	93
K	DRY	100	1.0	0.1	1	96	94	96	95
L	DRY	100	1.5	0.2	2	91	89	94	91
M	DRY	150	0.5	0.2	3	93	92	97	94
N	DRY	150	1.0	0.3	1	92	93	96	94
O	DRY	150	1.5	0.1	2	90	90	89	90
P	DRY	200	0.5	0.3	2	89	91	90	90
Q	DRY	200	1.0	0.1	3	89	90	89	89
R	DRY	200	1.5	0.2	1	89	91	90	90

The results for surface hardness (HRB) are analyzed using ANOVA in Minitab 17 software. As larger value of surface hardness is the requirement in experimentation so the criterion for evaluation "larger is better" is used. Table 5.2 summarizes the information of analysis of variance and case statistics for further interpretation.

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Table 5.2 Analysis of Variance for means of SN ratio for HRB (Larger is better)

Source	DF	SEQ SS	ADJ SS	ADJ MS	F	P	Percentage Contribution
Condition	1	0.163407	0.163407	0.163407	5.64	0.141	22
Speed	2	0.246777	0.246777	0.123388	4.26	0.19	34
Feed	2	0.029365	0.035933	0.017966	0.62	0.617	4
Depth of Penetration	2	0.006694	0.006694	0.003347	0.12	0.897	1
Number of Passes	2	0.064044	0.064044	0.032022	1.1	0.475	9
Condition*Speed	2	0.029569	0.029569	0.014784	0.51	0.662	4
Condition*Depth of Penetration	2	0.033081	0.000059	0.00003	0	0.999	5
Condition*Number of Passes	2	0.097988	0.097988	0.048994	1.69	0.372	13
Residual Error	2	0.057984	0.057984	0.028992			8
Total	17	0.728908					100

ANOVA table for surface hardness clearly indicates that the burnishing feed and depth of penetration are relatively less influencing factors for surface hardness and burnishing condition, burnishing speed and numbers of passes are the most influencing factors for surface hardness. Interaction between burnishing condition and number of pass, are also influencing surface hardness.

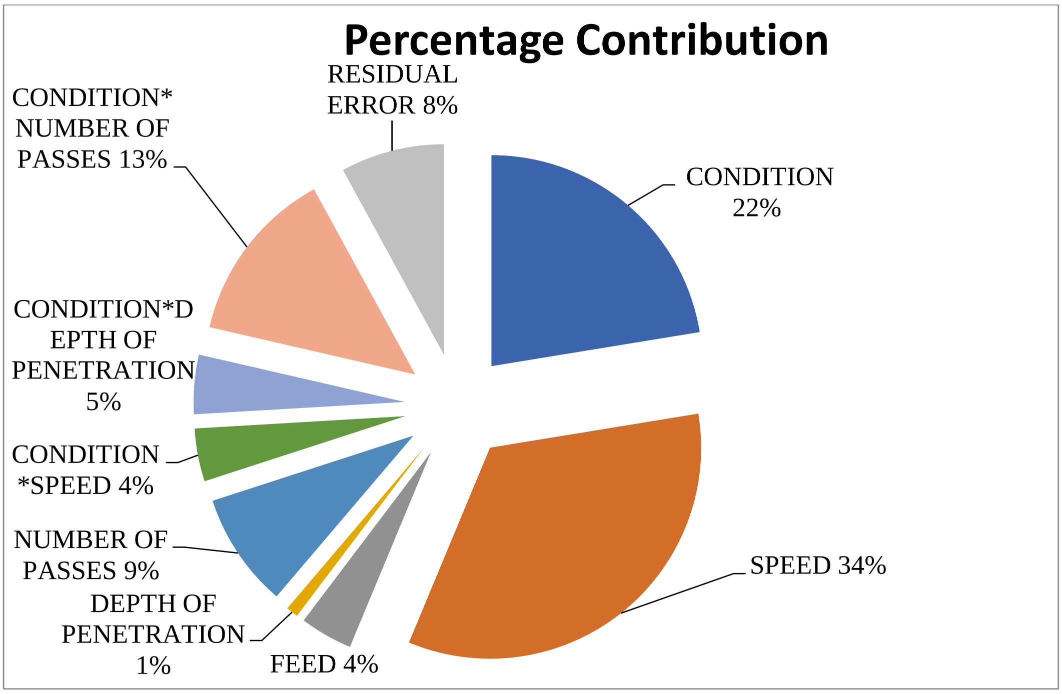

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Figure 5.1 Percentage contributions towards surface hardness

From the percentage contribution pie chart it is concluded that the burnishing speed is contributing maximum up to 34% , condition is contributing up to 22 % whereas no. of passes contribute 9% and depth of penetration has least contribution up to 1 % in surface hardness of 20MnCr5 steel. On the other end the combined effect the interaction between no. of passes and condition is also significant.

During the burnishing process the effect of different parameters like condition, speed, feed, Depth of penetration and number of passes on surface hardness in terms of SN ratio is shown in Figure 5.5.

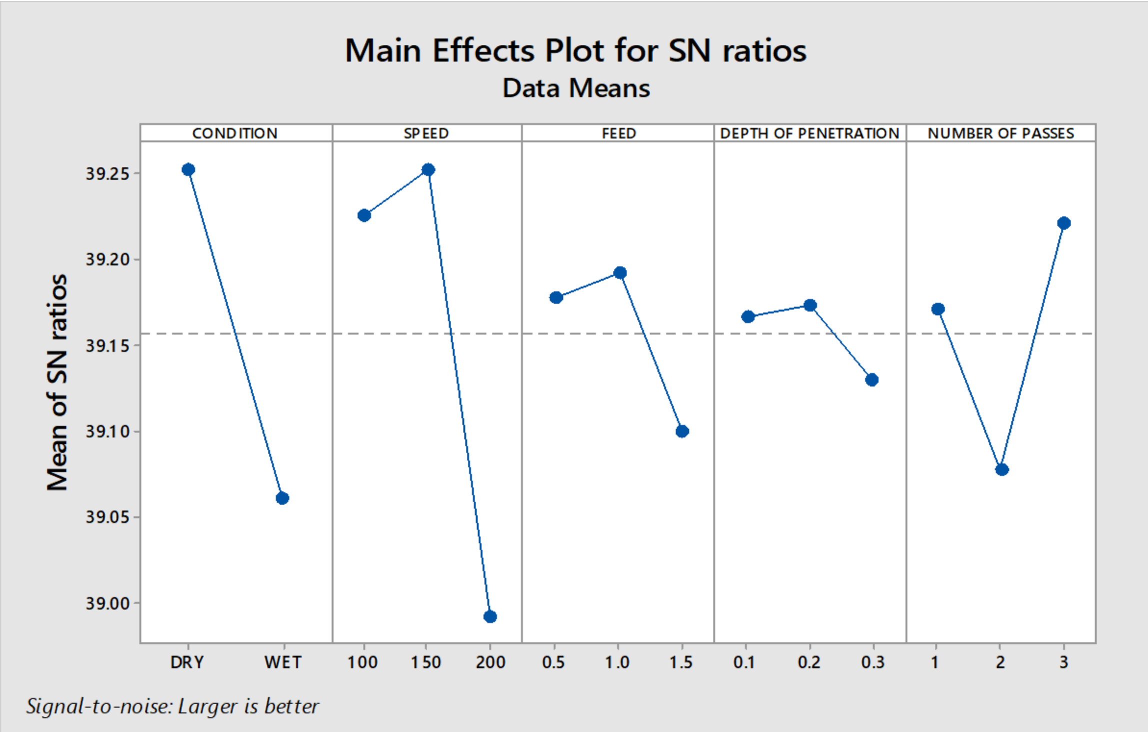

Figure 5.2 Main effects plot for SN ratios (HRB)

As per Figure 5.2 Main effects plot for SN ratios, Surface Hardness (HRB) is maximum at the 3rdlevel of no. of passes ,2ndlevel of condition, 2nd level of burnishing speed, 2nd level of peak burnishing feed and 2nd level of depth of penetration . From the Main effect plots for SN ratios it is observed that these levels of the parameters as best levels for maximum surface hardness (HRB) as shown in Table 5.3

Table 5.3 Levels of parameters at maximum Surface Hardness (HRB)

Factor	Condition	Speed	Feed	Depth of penetration	Number of passes
Level	2	2	2	2	3

Surface hardness is an important factor for different industrial application and this high value get observed when experimentation is done at maximum number of passes

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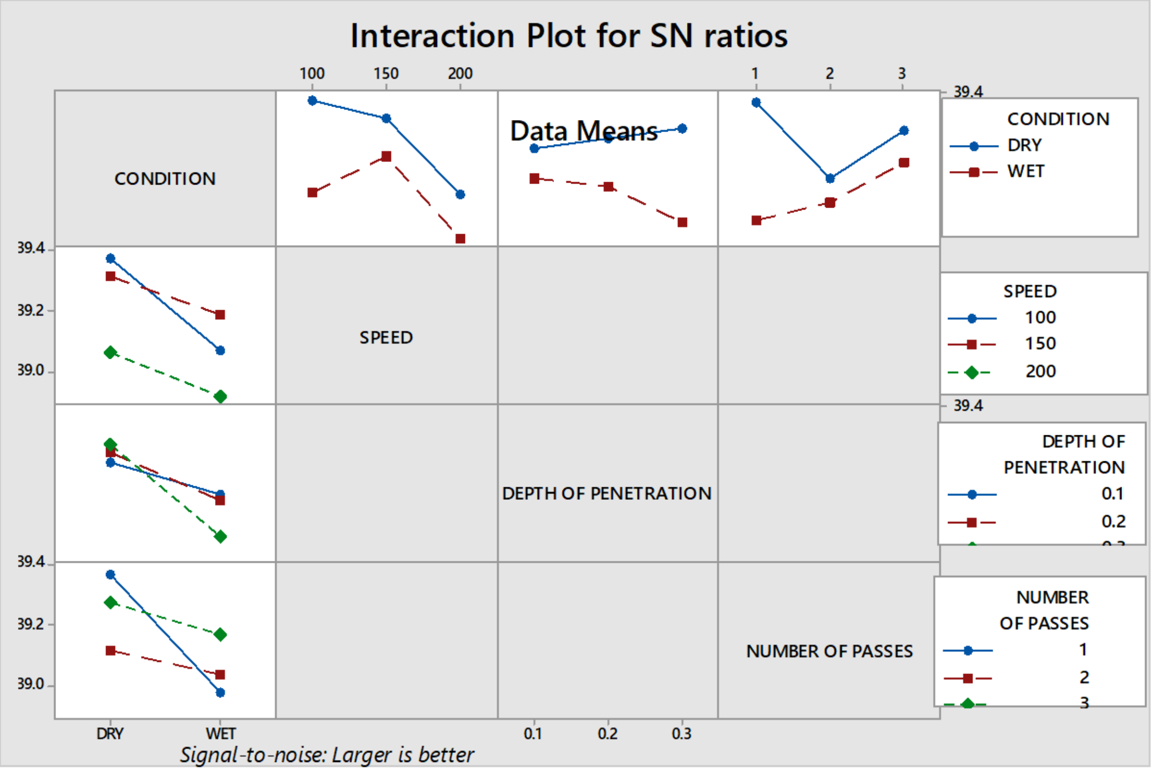

Figure 5.3 Interaction Plot for SN Ratios (Larger the better)

From the ANOVA table and interaction plot it is concluded that only the interaction between no. of passes and condition is significant.

. REFERENCES

[1]. Babu P Ravindra, Prasad T Siva, Raju A V S, Babu A Jawahar (2008), “Effects of internal roller burnishing on surface roughness and surface hardness of mild steel”, Journal of Scientific & Industrial Research, vol. 68, pp.29-31.

[2]. Babu P. Ravindra Ankamma, K.Prasad, T. Siva Raju A. V. S. and Prasad N. Eswara (2012), “Optimization of burnishing parameters and determination of select surface characteristics in engineering materials”, Indian Academy of Sciences, Vol. 37, Part 4, pp. 503–520.

[3]. Babu P. Ravindra, Ankamma K., Prasad T. Siva, Raju A.V. S., Prasad N. Eswara (2012), “Optimization of burnishing parameters by DOE and surface roughness, microstructure and micro hardness characteristics of AA6061 aluminium alloy in T6 condition”, International Journal of Engineering Research and Applications, vol. 2, no. 2, pp.1139-1146.

[4]. BouzidW. Tsoumarev O. and Saı K. (2004), “An investigation of surface roughness of burnished AISI 1042 steel”, vol.24, pp.120-125.

[5]. El-Axir M.H. (2000), “An investigation into roller burnishing”, International Journal Machine Tools Manufacture, vol.40, pp. 1603-1617.

[6]. El-Axir, Ibrahim (2005), “Some surface characteristics due to center rest ball burnishing”, Journal of Materials Processing Technology, vol. 167, pp.47-53.

[7]. El-Khabeery M.M., El-Axir M.H. (2001), "Experimental techniques for studying the effects of milling-roller burnishing parameters on surface integrity", International Journal of Machine Tools and Manufacture, vol. 41, pp. 1705- 1719.

[8]. El-Taweel T. A.and El-AxirM. H(2009), "Analysis and optimization of the ball burnishing process through the Taguchi technique", The International Journal of Advanced Manufacturing Technology, vol. 41, no 3-4, pp. 301-310.

[9]. El-Tayeb N.S.M., Low K.O., Brevern P.V. (2007), "Influence of roller burnishing contact width and burnishing orientation on surface quality and tribological behavior of aluminum 6061", Journal of Material Processing Technology, vol. 186, pp.272-278.

[10]. Gazan G.A. (1966), "Better hole by ballizing tool manufacturing", ENQ 57.

[11]. Ghani J.A, Choudhury I.A., Hassan H.H. (2004), "Application of taguchi method in the optimization of end milling parameters", Journal of Materials Processing Technology, vol.145, pp.84-92.

[12]. Hassan A.M., Al-Jalil H.F. and Ebied A.A. (1998)," Burnishing force and number of ball passesfor the optimum surface finish of brass components", Journal of Materials Processing Technology, vol. 83, pp. 176-179.

[13]. Hassan Adel Mahmood (1996), "The effects of ball- and roller-burnishing on the surface roughness and hardness of some non-ferrous metals", Journal of Materials Processing Technology, vol. 72, pp. 385-391.

[14]. John M R Stalin, Vinayagam B K (2011), "Investigation of roller burnishing process on aluminium 63400 material", Australian Journal of Mechanical Engineering, vol. 8, pp.47-54.

[15]. Kalsi S.B.S (2009), "Experimental investigation into the surface characteristics of burnished EN-31",M.Tech. Thesis submitted to Punjab Technical University, Jalandhar.

[16]. Kamble1P. S., Jadhav V. S. (2012) , "Experimental study of roller burnishing process on plain carrier of planetary type gear box", International Journal of Modern Engineering Research, vol. 2, no. 5, pp.3379-3383.

[17]. Klocke F. and Liermann J. (1998), "Roller burnishing of hard turned surfaces", International Journal of Machine Tools and Manufacture, vol. 38, no. 5-6, pp.419-423.

[18]. Korzynskia Mieczyslaw, Pacana Andrzej(2010), "Centre less burnishing and influence of its parameters on machining effects", Journal of Materials Processing Technology, vol. 210, pp.1217-1223.

[19]. Loh N.H., Tam S.C. and MiyazawaS. (1993), "Ball burnishing of tool steel", precision engineering, vol. 15, no. 2, pp. 100-105.

[20]. Loh, N.H., S.C. Tam and S. Miyazawa (1989), "Statistical analyses of the effects of ball burnishing parameters on surface hardness", Wear, pp. 129- 235.

[21]. Loh. N.H. and Tam, S.C. (1988), "Effect of ball burnishing parameters on surface finish, A literature survey and Discussion", Precision Engineering, pp. 215-220.

[22]. Murthy R.L., Kotiveerachari B. (1981), "Burnishing of metallic surfaces – a review", Precision Engineering, vol. 3, pp. 172-179.

[23]. Pande, S.S.; Patil, S.M. (1984), "Investigations on vibratory burnishing processes", International Journal Machine Tool Design, vol. 24 no. 3, pp. 195-206.

[24]. Patel Nikunj k, Patel Kiran A (2013), "Parametric optimization of process parameter for roller burnishing process: A Review", International Journal of Advanced Engineering Research and Studies, vol.2, no. 2, pp.53-56.

[25]. PrabhuP. R., KulkarniS. M., SharmaS. S. (2010), "Influence of deep cold rolling and low plasticity burnishing on surface hardness and surface roughness of AISI 4140 steel", World Academy of Science, Engineering and Technology, vol. 48, pp.619-624.

[26]. RajaseKariahR., Vaidyana than S. (1975), "Increasing the wear resistance of steel componentsby ball burnishing", Wear 43, pp. 183-188.

[27]. Rodríguez A., López deLacalleL.N., CelayaA., Lamikiz A. and Albizuri J. (2011), "Surface improvement of shafts by the deepball-burnishing technique", Surface & Coatings Technology, vol. 206, pp.2817-2824.

[28]. Roy, R.K. (1990), "Competitive manufacturing series", Van Nostr and Reinhold, New York.

[29]. Sagbas Aysun (2011), "Analysis and optimization of surface roughness in the ball burnishing process using response surface methodology and desirability function", Advances in Engineering Software, vol.42, pp. 992-998.

[30]. Shiou Fang-Jung, Chen Chien-Hua (2003), "Freeform surface finish of plastic injection mold by using ball-burnishing process", Journal of Materials Processing Technology, vol. 140, pp.248-254.

[31]. Shu Yang (2012),"Cryogenic burnishing of co-cr-mo biomedical alloy for enhanced surface integrity and improved wear performance",Doctoral thesis, College of Engineering at the University of Kentucky.

[32]. Stefan Dzionk, Wlodzimierz Przybylski (2012), "Surface waviness ofcomponents machined by burnishing method", Committee of Mechanical Engineering Pas-Poznan Division, vol. 32, no.3, pp. 25-33.

[33]. Sundararajan P.N. (2009), "Optimization of roller burnishing process for aluminum using taguchi technique", Master's thesis,S.R.M. UNIVERSITY,S.R.M. Nagar, Kattankulathur, Kanchipuram India.

[34]. Swirad Slawomir (2007), "The effect of burnishing parameters on steel fatigue strength", Nonconventional Technologies Review .No. 1.

[35]. ThamizhmnaiiS., OmarB. Bin, SaparudinS., HasanS. (2008), "Surface roughness investigation and hardness by burnishing on titanium alloy", Journal of Achievements in Materials and Manufacturing Engineering, vol. 28, pp.139-142.

[36]. UgurEsme, Mustafa Kemal Kulekci, SuedaOzgun, Yigit Kazancoglu (2013), "Predictive modeling of ball burnishing process", MP Materials Testing, vol. 3, pp.187-192.

[37]. Yeldose Binu C., Ramamoorthy B. (2008), "An investigation into the high performance of TiN-coated rollers in burnishing process", Journal of Material Processing Technology, vol. 207, pp.350-355.

[38]. YenY.C., SartkulvanichP.,AltanT. (2005), "Finite element modeling of roller burnishing process" CIRP Annals, Vol. 54/1, Pages 237-240.

[39]. Yinggang Tian, Yung C.Shin (2007), "Laser assisted burnishing", International Journal of Machine Tools, vol.47, issue 1, p.p. 14-22.

[40]. Grzesik W, Żak K. Producing high quality hardened parts using sequential hard turning and ball burnishing operations. Precision Engineering. 2013 Oct 31;37(4):849-55.

[41]. AKKURT A, Abdullah KU, ÖZDEMİR A, ŞEKER U. Comparison of hole surface finishing processes with roller burnishing method applied in copper materials. Gazi University Journal of Science. 2014;27(1):721-34.

[42]. Okada M, Suenobu S, Watanabe K, Yamashita Y, Asakawa N. Development and burnishing characteristics of roller burnishing method with rolling and sliding effects. Mechatronics. 2015 Aug 31; 29:110-8.

[43]. Zhang T, Bugtai N, Marinescu ID. Burnishing of aerospace alloy: a theoretical–experimental approach. Journal of Manufacturing Systems. 2015 Oct 31; 37:472-8.

[44]. Al Quran FM. The effect of roller burnishing on surface hardness and roughness of aluminum alloy. International Journal of Mechanics and Applications. 2015;5(2):37-40

[45]. John MS, Wilson AW, Bhardwaj AP, Abraham A, Vinayagam BK. An investigation of ball burnishing process on CNC lathes using finite element analysis. Simulation Modelling Practice and Theory. 2016 Mar 31;62:88-101.

[46]. Himanshu Khanna, Harish Pungotra, Sandeep Gandotra. OPTIMIZATION OF BURNISHING PROCESS PARAMETERS ON DIFFERENTLY HARDENED 20MnCr5 STEEL, International Journal of Mechanical and Production Engineering, ISSN(p): 2320-2092, ISSN(e): 2321-2071 Volume- 6, Issue-4, Apr.-2018

[47]. Harish, N., &Shivalingappa, D. (2020). The influence of ball and roller burnishing process parameters on surface integrity of Al 2024 alloy. *Materials Today: Proceedings*, *27*, 1337–1340. https://doi.org/10.1016/j.matpr.2020.02.614

[48]. Khanna Himanshu,|SinghHarminder,YadavSurendra Singh**Optimization of Roller Burnishing Process for Industrial Applications,** Published by LAP Lambert Academic Publishing, 2023, ISBN 10: 6206780643 / ISBN 13: 9786206780649