Comprehensive Study of Surface Roughness Model of Workpiece in Grinding Process

Do Duc Trung
Hanoi University of Industry, No. 298, Cau Dien Street, Bac Tu Liem District, Hanoi, Vietnam
doductrung@haui.edu.vn

Tran Thi Thu Hang
College of Economics and Technology, Group 15,Thinh Dan Ward, Thai Nguyen City, Viet Nam
thuhanghoc@gmail.com

***Abstract*—This article presents a comprehensive study of surface roughness model of workpieces in grinding process. Studies show that cutting parameters are often chosen as input parameters to build surface roughness model. However, the surface roughness model in each processing condition has different values. As a result, this study has proposed a method for building a surface roughness model of a workpiece when studying the grinding process by experimental method.**

Keywords—grinding process, surface roughness model, RSM

I. INTRODUCTION

The surface roughness of a workpiece is a very important parameter to evaluate the surface quality of the workpiece. When the surface of a machine part is machined by grinding, the surface roughness of the part is more clearly shown as an important parameter, because grinding is often the final processing method for surfaces of workpiece that require small surface roughness. For the purpose of processing the surface of the workpiece with small roughness, many studies have been published. Among those studies, the authors usually focus on two methods. *Firstly*, building a surface roughness model of a workpiece based on theoretical studies [1-13]. *Secondly*, building a surface roughness model of a workpiece based on experimental studies. With empirical methods, studies often give the surface roughness model of the workpiece in the form of regression equations which show the relationship between the surface roughness of the workpiece and the parameters of machining process. From that relationship, we can determine the value of technological parameters to process the surface of the workpiece in order to achieve the required surface roughness value. This method is commonly known as the Response Surface Method (RSM).

This article conducts the comprehensive study of some surface roughness models in published studies, thereby determining the parameters which are commonly used as input parameters when studying surface roughness by RSM.

II. RESPONSE SURFACE METHOD

Response surface method (RSM) is a combination of statistical theory and mathematical model, which is very useful in the modelling and analysing the technical problems. The main objective of RSM is to determine the optimum value of the target surface affected by many different initial parameters. Furthermore, RSM also allows control of input parameters to ensure the surface reaches a certain value. In RSM, the relationship between desired response and the input parameters is expressed in the following form [14, 15].

$$Y = F(x_i) \qquad (1)$$

For the specific case of this study, Y is the surface roughness value of the part; F is the response function; x_i is input parameter. In engineering, most of the relationship between the target surface roughness and the input parameters can be expressed and represented by a second order model [14]. This model works quite well across the entire range of input variables. Consequently, the expression (1) is written in the following form.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_i x_i^2 + \sum_i \sum_j \beta_{ij} x_i x_j + \varepsilon \qquad (2)$$

In which: $'Y'$ is corresponding response; x_i is (i^{th}) value of the input parameters; the quantities β are regression coefficients; ε is residual measure.

III. LITELATURE OVERVIEW

Table 1 presents a summary of some published studies on surface roughness of workpieces in grinding process, including: type of grinding wheel, type of processing materials, method of grinding, input parameters, conclusions or comments made in those studies. Table 2 presents some roughness models of the workpiece (regression model) corresponding to the studies mentioned in Table 1.

Table 1. Summary of some published studies

Conclusions/Discussions	Eq. in Table 2	Grinding wheel	Workpiece material	Grinding method	Ref.
- The error between experimental and predicted values at the optimal combination of parameter settings for within 4.30%. - The optimal combination of parameter settings are wheel speed of 850RPM, table speed of 15m/min and depth of cut of 11.94µm for achieving the required minimum surface roughness.	(3)	Al_2O_3 wheel	EN 24 steel	surface grinding	[16]
The feed rate and depth of cut have significant effects on surface roughness values.		Al_2O_3 wheel	OHNS	cylindrical grinding	[17]
- First order surface roughness model may be adequate for cylindrical grinding operation with perameters work speed, feed and depth of cut. The job dimensions and the parameters for experiments can be fixed after selecting the machine, the work material and the grinding wheel. - A second-order response surface model for surface roughness can be developed from the observed data. This will give 95% confidence level for the model. - Response surface methodology provides a large amount of information with a small amount of experimentation.		-	-	cylindrical grinding	[18]
- A second-order response surface model for surface roughness has been developed from the observed data. The predicted and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness on the machining of MMCs with 95% confidence intervals. Using such model, one can obtain a remarkable savings in time and cost. - Increasing the hardness, improves surface finish of workpiece. - Response surface methodology provides a large amount of information with a small amount of experimentation.	(4)	-	6061Al	cylindrical grinding	[19]
The depth of cut followed by flow rate and nozzle angle was most influencing parameters on surface roughness and material removal also.		A60 M6 VCNM	SAE 8620 grade steel	cylindrial grinding	[20]
All of input parameters have a significant effect on surface roughness.	(5)	22A60L6V6 3L	9SMn28	centerless grinding	[21]
The depth of cut has a greater effect on the surface roughness and feed has a medium effect while dressing depth of cut has minimal	(6)	A60V5V	AISI 1080	surface grinding	[22]

effect on surface roughness. Therefore, huge care has to be taken while selecting depth of cut in the grinding process.					
- The depth cut was influenced the out range of surface roughness. When depth of cut is minimum the value of surface roughness is also minimum. Based in the input and output results can predict the optimal value of surface roughness that derived in the final equation.	(7)	-	AISI 4140 Steel	cylindrical grinding	[14]
All of input parameters have a significant effect on surface roughness	(8)	SiC grain	-	grinding and polishing process	[23]
All of input parameters have a significant effect on surface roughness.	(9)	green silicon carbide with grit size of 120 microns	D2 steel	work roll grinding	[24]
- The feed rate and depth of cut had significant effects on surface roughness during the micro-grinding process, but their behaviours were different. The surface roughness values increased monotonically with increase in the feed rate. - By contrast, the response surface of the surface roughness in terms of depth of cut and air temperature had a saddle shape, which is very different from that for feed rate and air temperature.	(10)	CBN grinding wheel with grain size of 270	SK-41C tool steel	micro-grinding process with compressed air	[25]
All of input parameters have a significant effect on surface roughness.	(11)	A460L5V20	SS430 Material	cylindrical grinding	[26]
- When depth of cut and spindle speed is increased the MRR is increased and the grits become dull. The dull grits led to raised grinding force and effect the geometry of work surface. Such conditions present excessive heating of surface, burn marks and may be small cracks. - It is possible to predict the surface roughness and material removal rate before conducing grinding process.		Al_2O_3 wheel	OHNS Material	cylindrical grinding	[27]
All of input parameters have a significant effect on surface roughness.	(12)	Cn80.TB$_1$.G.V$_1$.500.150. 305x35m/s	20X-carbon infiltration steel	plunge centerless grinding	[28]
The mathematical models can be successfully used to predict the surface roughness value for any combination of the feed rate, grit size, cutting speed and depth of cut within the range of the performed experimentation.	(13)	-	Europen black pine	sanding	[29]
- The surface roughness increases with an	(14)	metallic	OFSiC	surface	[30]

increase in feed and depth of cut. When the feed and depth of cut are increased, the increase in material removal rate and the increase in chip thickness account for the increase of surface roughness - Surface roughness decreases with an increase in wheel speed.		bonded diamond grinding wheel	advanced ceramic material	grinding	
All of input parameters have a significant effect on surface roughness	(15)	CBN wheel	AISI 1045 steel	cylindrical grinding	[31]
- The cutting fluid (water soluble oil) was most influencing factor for EN8 materials followed by work piece speed and depth of cut. - Higher work piece speed and higher the depth of cut improves surface finish when grinding in water soluble oil. With emulsion coolant, better surface finish is obtained at higher work piece speed and higher depth of cut with manual feed. - Water soluble oil contain higher flow ability with a medium viscosity, when pure oil gives poor flow ability with a high viscosity and pure water gives higher flow ability with poor viscosity. this study shows that, due to high flow ability and medium viscosity gives maximum value of surface roughness. - Water soluble oil gives better surface roughness than pure water due to oil smoothened cutting action. Pure oil gives higher surface roughness than water soluble oil because it only contains high viscosity oil cutting action. - As the work piece speed increases the rubbing of the abrasive grain also increased and it leads to reduced surface roughness. Depth of cut increases from lowest to highest level, surface roughness was reduced.	(16)	Aluminum oxide White grinding wheel	EN8 material	cylindrical grinding	[32]
In dry grinding process, the depth of cut if found to be significant in ANOVA of surface roughness.	(17)	SiC	AISI1040 Steel	surface grinding, using MQL technique	[33]
- Cylindrical grinding is a finest method to produce improved surface quality in machined components. Whenever the input parameters get deflected, it reflects on the outcome of the component. It may be depth of cut, cutting speed. - In bronze and gunmetal materials, increasing depth of cut reduces the surface finish of component.		Mg+SiC+Isopolymer; Cu+Sand+ Epoxy	GUN material	cylindrical grinding	[34]
- For EN-31 material in case of without hardening, the mean average roughness shows that depth of cut contributes highest effect on the surface roughness, followed by table speed	(18)	-	EN-31 material	surface grinding	[35]

and coolant flow rate. - For EN31 with hardening, the mean average roughness shows that table speed contributes highest effect on the surface roughness, followed by depth of cut and coolant flow rate					
All of input parameters have a significant effect on surface roughness		-	En15AM steel	centerless grinding	[36]
Traverse speed and the depth of cut are significant factors that affect the surface roughness of Inconel 718. However, the number of passes does not seem to have any significant effect. The traverse speed is the most significant factor that affects the surface roughness of Inconel 718, followed by the depth of cut.	(19)	-	Inconel 718 material	surface grinding	[37]

Table 2. Surface roughness models

Regression model	Input parameters	Eq.
$R_a = 3.10845 * N_G - 0.031132 * v_W - 0.021647 * t$ $+0.00000 * N_G^2 + 0.00265 * v_W * t$	N_G is grinding wheel speed [rev/min]; v_W is table speed [m/min]; t is depth of cut [mm]	(3)
$R_a = 7.76969 - 0.119088 * A - 7.86756 * B$ $-0.00101748 * C + 0.00051371 * A^2$ $-7.95455 * B^2 - 3.13131 * 10^{-7} * C^2$ $+0.0240385 * A * B + 1.37821 * 10^{-5} * A * C$ $+0.003125 * B * C$	A is Hardness [BHN]; B is depth of cut [mm]; C is flow rate [ml/min]	(4)
$R_a = 1.22 + 0.041 * h + 0.27 * f_d$ $-4.722 * 10^{-3} * n_r + 0.035 * v_{fa} - 0.07 * h^2$ $-0.09 * f_d^2 - 0.069 * n_r^2 - 0.027 * v_{fa}^2$ $+1.25 * 10^{-3} * h * f_d + 7.917 * 10^{-3} * h * n_r$ $+1.25 * 10^{-3} * h * v_{fa} + 1.25 * 10^{-3} * f_d * n_r$ $+4.167 * 10^{-4} * f_d * v_{fa} + 0.02 * n_r * v_{fa}$	h is component height [mm]; f_d is dressing feed-rate [mm/min]; n_r is control wheel speed [rev/min]; v_{fa} is In-feed speed [m/s]	(5)
$R_a = 0.39375 - 4.385 * D - 0.345 * F$ $+0.325 * D_d + 2 * D * F + 5 * D * D_d - 5 * F * D_d$ $+19.3 * D^2 + 0.575 * F^2 + 32.5 * D_d^2$	D is depth of cut [mm]; F is feed rate [mm]; D_d is dressing depth of cut [mm]	(6)
$R_a = 0.17683 + 4.89633 * 10^{-4} * N$ $+1.75037 * D + 4.72369 * 10^{-3} * T$	N is workpiece speed [rev/min]; D is depth of cut [µm]; T is time [min]	(7)
$R_a = 1.20772 - 2.74927 * 10^{-3} * P$ $-0.24117 * \mathrm{F} - 0.075175 * V_s + 0.2705 * V_w$ $+8.284 * 10^{-6} * P^2 + 0.049825 * F^2$ $+3.11404 * 10^{-3} * V_s^2 + 0.74561 * V_w^2$ $-1.66667 * 10^{-4} * P * F$ $+4.16667 * 10^{-5} * P * V_s - 1.25 * 10^{-3} * P * V_w$ $+6.07153 * 10^{-18} * F * V_s$ $-0.025 * F * V_w - 0.01875 * V_s * V_w$	P is abrasive size; F contact force [F/N]; V_s is belt linear velocity [m/s]; V_w is feed rate [m/min]	(8)

$R_a = 0.0786 - 0.0042 * W_s - 0.00079 * J_s + 0.0025 * T_s + 0.0024 * d - 0.0022 * D_p + 0.0021 * D_s - 0.0036 * W_s^2 - 0.000486 * J_s^2 - 0.000944 * T_s^2 + 0.0032 * d^2 - 0.0024 * D_p^2 - 0.00082 * D_s^2 - 0.0027 * W_s * J_s + 0.0015 * W_s * T_s + 0.00025 * W_s * d - 0.00125 * W_s * D_p - 0.0002 * W_s * D_s + 0.00025 * J_s * T_s - 0.0015 * J_2 * d + 0.0034 * J_s * D_p - 0.00137 * J_s * D_s + 0.00012 * T_s * d - 0.0015 * T_s * D_p - 0.00031 * T_s * D_s - 0.0045 * d * D_p - 0.000375 * d * D_s - 0.00137 * D_p * D_s$	W_s is wheel speed [rev/min]; J_s is work speed [rev/min]; T_s is traverse speed [m/min]; d is in-feed [μm]; D_p is dress depth [μm]; D_s is dress lead [m/min]	(9)
$R_a = 7.59375 * 10^{-5} * d^2 - 1.06389 * 10^{-5} * f^2 - 7.969 * 10^{-7} * A^2 + 3.411 * 10^{-3} * d + 2.87713 * 10^{-3} * f + 1.55795 * 10^{-1} * A - 2.97396 * 10^{-6} * d * f - 1.59937 * 10^{-4} * d * A + 1.75438 * 10^{-4} * f * A - 0.596705$	d is depth of cut [mm]; f is feed rate [mm/min]; A is air temperature [^{0}C]	(10)
$R_a = 0.1287 + 10.18 * d + 0.003477 * R + 0.00248 * f - 476 * d^2 + 0.000009 * R^2 - 0.000118 * f^2 + 0.0346 * d * R + 0.2889 * d * f + 0.000007 * R * f$	d is depth of cut [mm]; R is job rotating speed [rev/min]; f is feed rate [mm/s]	(11)
$R_a = 0.414 - 0.065833 * \beta + 0.2275 * S_{sd} + 0.083333 * S_k - 0.0575 * v_{dd} + 0.088792 * \beta^2 + 0.113792 * S_{sd}^2 + 0.073792 * S_k^2 + 0.026292 * v_{dd}^2 - 0.03875 * \beta * S_{sd} + 0.065 * \beta * S_k + 0.01625 * \beta * v_{dd} - 0.035 * S_{sd} * S_k - 0.07875 * S_{sd} * v_{dd} + 0.0275 * S_k * v_{dd}$	β is center height angle [^{0}]; S_{sd} is dressing feed-rate [mm/min]; S_k is feed speed [μm/s]; v_{dd} is control wheel velocity [m/min]	(12)
$R_a = 23.73 - 0.0372 * p - 0.649 * f + 0.16 * d - 0.973 * s + 0.000126 * p^2 + 0.02009 * f^2 + 0.00509 * d^2 + 0.02830 * s^2 + 0.001417 * p * f - 0.001958 * p * d - 0.000979 * p * s + 0.01469 * f * d - 0.00109 * f * s + 0.00189 * d * s$	f is feed rate [m/min]; s is cutting speed [m/s]; d is depth of cut [mm]; p is grit size	(13)
$R_a = 0.26021 + 0.012099 * F - 0.93651 * D - 1.94444 * 10^{-5} * N + 9.01587 * D^2$	F is table feed [m/min]; D is depth of cut [mm]; N is wheel speed [rev/min]	(14)
$R_a = -0.3845 - 0.00459 * a_0 + 0.04408 * v_s + 9.275 * v_w - 0.00001 * a_0^2 - 0.00019 * a_0 * v_s + 0.1975 * a_0 * v_w - 0.56652 * v_w * v_s$	a_0 is infeed [μm]; v_s is wheel speed [m/s]; v_w is work speed [m/s]	(15)
$R_a = 0.695 - 0.00077 * N - 0.00019 * d$	D is work piece speed [rev/min]; d is depth of cut [μm]	(16)
$R_a = 0.646 - 0.0539 * A + 4.916 * 10^{-4} * B + 0.018 * C + 6.498 * 10^{-3} * D$	A is cutting speed [m/s]; B is depth of cut [μ]; C is table feed [m/min]; D is MQL with Nano particles [% by wt]	(17)
$R_a = 0.268 - 0.000015 * TS + 0.0032 * D - 0.00037 * CFR$	TS is table speed [mm/min]; D is depth of cut [μm];	(18)

	CFR is coolant flow rate [lit/min]	
$R_2 = 0.347 + 3.185 * 10^{-5} * A + 0.048 * B$ $+8.653 * 10^{-3} * C$	A is traverse speed; B is depth of cut; C is the number of passes	(19)

The data in tables 1 and 2 show that: (1) The studies often select the cutting parameters as input parameters in experimental studies to build a surface roughness model. (2) For most grinding methods (surface grinding, cylindrical grinding and centerless grinding), the commonly selected parameters are the cutting speed, the feed rate and the depth of cut. (3) In different processing conditions (grinding method, type of grinding wheel, material type of workpiece, and so on), roughness model has different form. At the same time, in those studies, the influence of the input parameters on the roughness of the workpiece is also different. Therefore, it is necessary to conduct experimental studies in each specific condition to build the surface roughness model of the part.

IV. CONCLUSIONS

Some conclusions drawn from this study are as follows:

1) Experimental studies to build a regression model showing the relationship between the surface roughness of the workpieces and the parameters of the machining process has been performed by many authors. However, in each specific processing condition, the regression model has different values.

2) The input parameters in published studies are usually the cutting parameters.

3) In each specific processing condition, in order to process the surface roughness of the workpiece to meet the requirements, experimental study can be carried out to build a surface roughness model with cutting parameters. The relationship will also help to determine the degree of influence of each parameter on the surface roughness, which is the basis for the control of the grinding process.

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REFERENCES

1. Rogelio L. Hecker, Steven Y. Liang (2003), Predictive modeling of surface roughness in grinding, International Journal of Machine Tools and Manufacture, **43**, pp.755–761
2. G.K. Lal, M.C. Shaw (1975), The role of grain tip radius in fine Journal of Engineering for Industry August, pp.1119–1125
3. K. Nakayama, M.C. Shaw (1968), Study of finish produced in surface grinding, part 2, Proceeding of the Institution of Mechanical Engineers, **182**
4. K. Sato (1955), On the surface roughness in grinding, Technology Reports, Tohoku University, **20**, pp.59–70
5. C. Yang, M.C. Shaw (1955), The grinding of titanium alloys, Transactions of ASME, **77**, pp.645–660
6. X. Zhou, F. Xi (2002), Modeling and predicting surface roughness of the grinding process, International Journal of Machine Tools and Manufacture, **42**, pp.969–977
7. P. Basuray, B. Sahay, G. Lal (1980), A simple model for evaluating surface, roughness in fine grinding, International Journal of Machine Tool Design and Research, **20**, pp.265–273
8. K. Steffens (1983), Closed loop simulation of grinding, Annals of CIRP, **32** (1), pp.255–259
9. Anne Venu Gopal, P. Venkateswara Rao (2004), A new chip-thickness model for performance assessment of silicon carbide grinding, Int J Adv Manuf Technol, **24**, pp.816–820
10. Sanchit Kumar Khare, Sanjay Agarwa (2015), Predictive modeling of surface roughness in grinding, 15th CIRP Conference on Modelling of Machining Operations, Procedia CIRP, **31**, pp.375–380
11. Sanjay Agarwal and P. Venkateswara Rao, Surfacce roughness prediction model for ceramic grinding (2005), ASME International Mechanical Engineering Congress and Exposition, Orlando, Florida USA, pp.1-9
12. Sanchit Kumar Khare and Sanjay Agarwal (2005), Predictive modeling of surface roughness in grinding, Procedia CIRP, **31**, pp.375–380
13. Krishna Kumar Saxena, Sanjay Agarwal and Raj Das, Surface Roughness Prediction in Grinding: a Probabilistic Approach (2016), MATEC Web of Conferences, **82**, 01019, pp.1-9
14. B. Radha Krishnan, R. Aravindh, M. Barathkumar, K. Gowtham, R.Hariharan (2018), Prediction of Surface Roughness (AISI 4140 Steel) in Cylindrical Grinding Operation by RSM, International journal for research & development in technology, **9** (3), pp. 702-704
15. Raymond H Myers, Douglas C Montgomery, and Christine M Anderson-Cook (2009), Response Surface Methodology (Process and Product Optimization Using Designed Experiments, John Wiley & Sons, Inc, 3rd Edition)
16. Pawan Kumar, Anish Kumar, Balinder Singh (2013), Optimization of Process Parameters in

Surface Grinding Using Response Surface Methodology, IJRMET, **3** (2), pp. 245-252

17. S. M. Deshmukh1, R. D. Shelke2 and C. V. Bhusare, Optimization of Cylindrical Grinding Process Parameters of Hardened Material using Response Surface Methodology (2016), International Journal of Innovative Science, Engineering & Technology, **3** (11), pp. 216-219
18. R. G. Jivani, P. M. George, B. S. Patel (2011), Dedign of experiments and response surface method in context to grinding process, National Conference on Recent Trends in Engineering & Technology.
19. Dayananda Pai, Shrikantha Rao, Raviraj Shetty and Rajesh Nayak (2010), Application of response surface method on surface roughness in grinding of aerospace materials (6061Al-15Vol%SiC25P), ARPN Journal of Engineering and Applied Sciences, **5** (6), pp.23-28
20. Hemant S. Yadav, R. K. Shrivastava (2014), Effect of Process Parameters on Surface Roughness and Mrr in Cylindrical Grinding using Response Surface Method, International Journal of Engineering Research & Technology, **3** (3), pp. 1384-1388
21. P. Krajnik, J. Kopac, A. Sluga (2005), Design of grinding factors based on response surface methodology, Journal of Materials Processing Technology, 162–163, pp.629–636
22. S.Periyasamy, M.Aravind, D.Vivek, K.S.Amirthagadeswaran (2014), Optimization of Surface Grinding Process Parameters for Minimum Surface Roughness in AISI 1080 Using Response Surface Methodology, Advanced Materials Research, 984-985, pp. 118-123
23. Tao Zhao, Yaoyao Shi, Xiaojun Lin, Jihao Duan, Pengcheng Sun, Jun Zhang (2014), Surface roughness prediction and parameters optimization in grinding and polishing process for IBR of aero-engine, Int J Adv Manuf Technol, DOI 10.1007/s00170-014-6020-3
24. N. Mohanasundararaju, R. Sivasubramanian, N. Alagumurthi (2008), Optimisation of work roll grinding using Response Surface Methodology and evolutionary algorithm, Int. J. Manufacturing Research, **3** (2), pp.236-251
25. P-H. Lee, H. Chung, S. W. Lee (2011), Optimization of micro-grinding process with compressed air using response surface methodology, Proc. IMechE, **225**, Part B: J. Engineering Manufacture
26. V. Saravanakumar, M. Viswanath, N. Thirumalaisamy (2016), Analysis of Surface Roughness and Machining Time in Cylindrical Grinding of SS430 Material Using Response Surface Method, International Journal of Engineering Trends and Technology, **42** (6), pp.271-280
27. S. M. Deshmukh, R. D. Shelke, C. V. Bhusare (2016), Optimization of Cylindrical Grinding Process Parameters of Hardened Material using Response Surface Methodology, International Journal of Innovative Science, Engineering & Technology, **3** (11), pp.216-219
28. Phan Bui Khoi, Ngo Cuong, Do Duc Trung (2014), A study on multi-objective optimization of plunge centerless grinding process, International journal of mechanical engineering and technology, **5** (11), pp.140-152
29. Ender Hazir, Kücük Hüseyin Koc, Salim Hiziroglu (2017), Optimization of sanding parameters using response surface methodology, Maderas. Ciencia y tecnología **19** (4), pp.407-416
30. Binu Thomas, Eby David, Manu R (2014), Modeling and optimization of surface roughness in surface grinding OFSiC advanced ceramic material, 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014), Assam, India, pp.333.1-311.7
31. Mamun A A, Dhar N R (2012), Numerical Modeling of Surface Roughness in Grinding under Minimum Quantity Lubricants (MQL) using Response Surface Method (RSM), Global Journal of Researches in Engineering Mechanical and Mechanics Engineering, **12** (5)
32. Suresh P. Thakor, D. M. Patel (2014), An Experimental Investigation on Cylindrical Grinding Process Parameters for En 8 Using Regression Analysis, International Journal of Engineering Development and Research, **2** (2), pp. 2486-2491
33. S. Sarika, K. Manikantesh, D. Pavan Kumar (2017), Experimental Investigation of Surface Roughness and Temperature On Surface Grinding of AISI1040 Steel using MQL Technique, International journal of scientific Engineering and Technology Research, **6** (2), pp.2364-2369
34. R.Baskar, A. Sam joseph, R. K. Sanjeevakumaran, B. Prakash, N. Pradeepan (2018), Investigation of surface roughness of grinding wheel for GUN materials, International Journal of Engineering, Science and Mathematics, **7** (4), pp.294-297
35. Omprakash Waikar, Swapnil Nikam, Rahul More, Shivam Shinde, Rahul Chakule (2017), Optimization of Machining Parameter for Surface Roughness, IOSR Journal of Mechanical and Civil Engineering , pp.25-30
36. Durairaj V. P, Venkatesh Babu (2017), Optimization of surface finish on grinding outer diameter, International Journal of Pure and Applied Mathematics, **116** (14), pp. 347-351
37. Nurul Afizan Yaakob, Hema Nanthini Ganesan, Nurul Hatiqah Harun, Raja Izamshah Raja Abdullah, Mohd Shahir Kasim (2017), Influence of Grinding Parameters on Surface Finish of Inconel 718, Journal of Mechanical Engineering, **3** (2), pp. 199-209