The Effects of Cylindrical Grinding Factors in the Production of Grinding Spindle using Hardened EN353 Steel

Manikandan.M, Prabagaran.S, Sivaram.N.M, Milon Selvam Dennison

Abstract: *The objective of this study is to produce the best possible grinding spindle using hardened EN 353 steel through the cylindrical grinding process. Primarily the EN 353 steel specimens are cut according to the product specification and subjected to rough machining. Then the steel specimens are subjected to a heat-treatment process to enhance the mechanical property hardness so that the specimen becomes wear-resistant. The experimental runs are planned based on Taguchi's $L_{27}(3^7)$ array and conducted in a cylindrical grinding machine (Toyoda G32 cylindrical grinding machine). The surface roughness of the machined specimens is measured using a calibrated surface roughness tester. A prediction model is created through regression analysis for the outcome. The significance of the selected grinding factors and their levels on surface roughness is found by analysis of variance (ANOVA) and F-test and finally, a affirmation test is conducted to confirm the optimum factors.*

Keywords: Grinding spindle; cylindrical grinding; EN 353; Taguchi; Regression analysis, ANOVA.

I. INTRODUCTION

Nowadays the preferred surface quality and geometry of raw material could be obtained by the most versatile production process known as machining [1]. Over 90% of all-out power benefited from the machine will change over into heat vitality, due to the relative development associated with the workpiece and cutting apparatus [2 – 3]. This type of heat vitality is viewed as waste and such type of created warmth causes poor item surface quality and device wear [4]. Along these lines, the extraordinary warmth generated could be reduced by applying cutting liquids on the device work interface [5].

The joined action of rubbing, ploughing and shearing off a multi-point cutting tool removing the small type of particles is called grinding [6-7].

Manikandan.M*, Research Scholar, Mechanical Engineering, Karpagam Academy of Higher Education, INDIA.
Email: kahemmk@gmail.com
Prabagaran.S, Professor, Mechanical Engineering, Karpagam Academy of Higher Education, INDIA.
Email: s.prabagaran.cbe@gmail.com
Sivaram.N.M, Mechanical Engineering, National Institute of Technology Puducherry, Karaikal, INDIA
Email: nmsivaram@gmail.com
Milon Selvam Dennison, Mechanical Engineering, Kampala International University, Kampala, UGANDA.
Email: milon.selvam@kiu.ac.ug

Aside from the determination of grinding process factors like wheel speed, table speed, depth of cut, the dressing parameters, for example, dresser tip radius, dressing feed, dressing angle, the number of passes and dressing depth are likewise significant for the better surface finish of the product [8-9]. With a lower depth of dressing and lower dressing feed, better grinding can be accomplished though with higher dressing depth and higher dressing feed coarser grinding can be accomplished without changing the grinding wheel [10-11]. Along these lines, recommending ideal dressing factors is required for a particular grit size, and the shape of the grinding wheel to get the required surface finish [12].

These days case-hardened steel is largely employed for different functions in aircraft and automotive industry. Machining of tough steel is a burdensome task and constantly analyzed by researchers and makers [11]. Numerous investigations have been carried out in the machining of harder steel alloy. Some of the investigation examples are presented below.

Asilturk et al. [13] have researched the outcome of machining factors on surface coarseness in hard machining by Taguchi's methodology. Selvaraj et al. [14] have discovered the effects of axle speed and feed on cutting force and device wear of two particular evaluations of nitrogen alloyed duplex hardened steel in dry machining. Abrao et al. [15] have underlined that feed is the major basic factor impacting the surface harshness rather than speed for both earthenware additions and CBN. The later kind of mechanical apparatus have been used by Davim et al. [16] to take a look at the machinability of steel. They have considered that with an appropriate choice of machining limitations it is possible to get a perfect surface completion. Benlahmidi et al. [17] have dissected the impact of control variables of cutting velocity, feed rate, profundity of cut and workpiece material hardness on surface coarseness, cutting weight, and cutting force during hard machining. The outcome reveals that surface harshness has more impact on cutting pace, feed rate, and workpiece material hardness.

From the study stated above, it seems certain there are problems in the machining of metal requiring additional investigation to find a sensible solution. The intent of this research work is to produce the best quality grinding spindle using hardened EN 353 steel through the cylindrical grinding process. The examination on grinding is done by making utilization of the demonstrated test structure strategy.

II. EXPERIMENT DETAILS

A. Workpiece

The cylindrical workpiece made of EN 353 steel was selected for this study. EN 353 steel is a Nickel-Chromium alloy steel with wear resistance properties and extensively used several applications such as significant duty gear, shaft, pinion, camshafts, grinding spindle and gudgeon pins. The geometry of the grinding spindle is shown in Figure 1. The chemical composition of EN 353 steel is shown in Table 1. The experimental methodology is depicted in Figure 2.
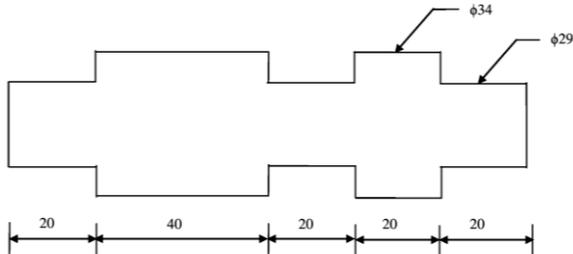
All dimensions are in mm

Figure 1: Geometry of the grinding spindle

Table 1: Chemical Composition of EN 353

Element	%Composition	
	Standard	*Tested*
Fe	95.195 - 96.33	95.3
Ni	1.00-1.50	1.42
Cr	0.75-1.25	1.21
Mn	0.50-1.00	0.87
C	0.10-0.20	0.80
Mo	0.08-0.15	0.13
Si	0.35maximum	0.27

B. Heat Treatment

The EN 353 rough-machined specimens were heat-treated following the standard ASTM D6200 – 01 [18]. They were heated gradually to 850^0C and subsequent to sufficient oil drenching at this temperature the specimens were put in a salt tub, which would lessen the chance of decarburization or scaling. Thus hardening of the EN 353 steel specimens was performed.

C. Grinding wheel

White Aluminium oxide grinding wheels of grades AA46/54-K5-V8, AA60-K5-V8, A80-K5-V10 of different wheel grit sizes 46, 60 and 80 were used to conduct this research work.
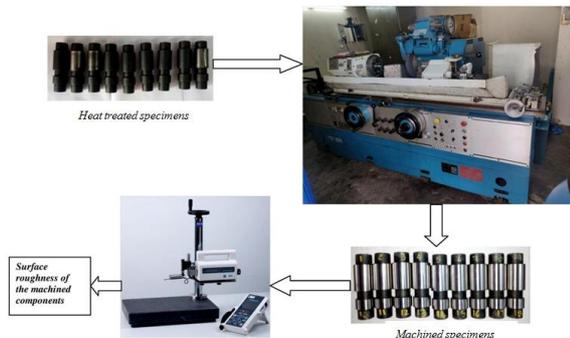

Figure 2: Experimental methodology

D. Cutting Fluid

Servosynth is water-dissolvable synthetic grinding fluids. The solutions prepared from these fluids are fully clear and free from any fatty matter. Servosynth emulsified with water was used as a cutting fluid for grinding the steel specimens. Properties of cutting fluid Servosynth grade oil are given in Table 2.

Table 2: Fluid Properties of Servosynth grade oil

Property	Value
Specific gravity	1.206
Kinematic Viscosity at 40^0C	60 cSt
Flash Point	150^0C

E. Experimental Conditions

A pilot study was conducted and the highly influencing machining factors were identified for the experimentation. The influencing machining factors on surface roughness are depicted through cause and effect diagram in Figure 3, and highly influencing factors are identified and their levels indicated in Table 3. The trials were arranged in view of Taguchi's orthogonal array in a cylindrical grinding machine (Toyoda G32). The conditions of the experimentation are specified in Table 4.
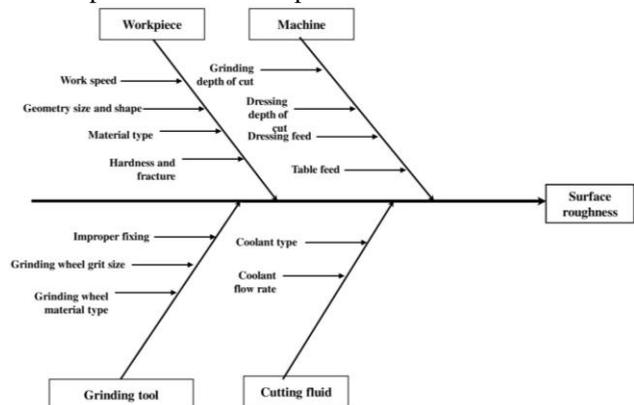

Figure 3: Cause and effect diagram

Table 3: Control factors and levels

Notation	Parameters	Unit	Levels		
			1	2	3
A	Wheel Grit Size	-	46	60	80
B	Work speed	m/min	10	14	18
C	Table feed, mm/rev of job	mm/rev	8	12	16
D	Grinding depth of cut	µm	12	18	24
E	Dressing feed	mm/min	170	220	270
F	Dressing depth of cut	µm	5	10	15
G	Coolant flow	*l*/min	30	40	50

Table 4: Experimental conditions

Workpiece used	EN 353
Grinding wheel	White Aluminium oxide of wheel grit sizes 46, 60 and 80
Machine tool	Toyoda G32 cylindrical grinding machine
Cutting fluid	Servosynth
Planning of the experiment	Taguchi's orthogonal array
Output response	Surface roughness

III.   RESULTS AND DISCUSSION

A.   Optimization by Taguchi Technique

A.1   S/N ratio calculation

The surface roughness of the turned samples was tested using a surface roughness tester (Carl Zeiss Surfcom 130A).

The quality attribute with the sort of '*smaller-the-better*' measured in this research work was surface roughness of the machined samples. The S/N ratio for the yield response was computed by using the following Equation (1) [19] for each machining condition and their values are given in Table 5, where, 'Ra' is the average surface roughness value of the trials Ra_1, Ra_2, Ra_3, Ra_4 of the single machined component.

$$S/N(dB) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Ra_i^2\right) \qquad (1)$$

where $i = 1, 2,\dots, n$ (here $n = 7$) and Ra_i is the response value.

The estimation of 'Prob.>F' in Table 6 for the model is under 0.05, which demonstrates that the model is significant, which is desirable as it shows that the terms in the model significantly affect the yield response. From ANOVA, it is evident that wheel grit size impacts more on the surface roughness, trailed by the work speed, dressing feed, coolant flow, dressing depth of cut, table feed mm/rev of job and grinding depth of cut, This is harmonizing with the current hypotheses of machining.

A.2   Effect of Machining Factors

From the ANOVA results, it is evident that the highly influencing factor on surface roughness is grinding wheel grit size. In the following section the interaction effect of grinding wheel grit size with other factors on surface roughness was studied and presented in the below section.

Figure 4 depicts the outcome of wheel grit size and work speed on the surface roughness, where the other factors are kept constant. From Figure 4 it is obvious that wheel grit size influences more than the work speed, the interaction of wheel grit size and work speed on the surface roughness is significant and also it is clear that, at the least wheel grit size minimum surface roughness was noted. Figure 5 depicts the outcome of wheel grit size and table feed on the surface roughness, where the other factors are kept constant. From Figure 5 it is observed that the interaction between wheel grit size and table feed on surface roughness found to be least significant. Similarly, Figure 6, Figure 7, Figure 8 and Figure 9 depicts the outcome of wheel grit size with grinding depth of cut, dressing feed, dressing depth of cut, coolant flow respectively on the surface roughness, where cutting velocity is kept constant. From Figure 6, Figure 7, Figure 8 and Figure 9 it is obvious that the interaction of factors on surface roughness found to be least significant.

A.3   Prediction model

By methods for relapse examination with the guide of MINITAB 17 factual programming, the impact of machining parameters on mean surface roughness (Ra) is displayed as given below.

Ra = 0.130 + 0.00401A + 0.0066B - 0.0088C - 0.00657D + 0.000352E + 0.0035F - 0.000883G - 0.000061AB - 0.000002AC + 0.000012AD - 0.000005AE - 0.000095AF - 0.000017BC + 0.000108BD - 0.000131BF - 0.000021BG + 0.00028 CD + 0.000430CF + 0.000019CG + 0.000074DF - 0.000015EF   (2)

For the above-forecast model, it is found that $R^2 = 0.99$, where 'R' is the relationship coefficient and the worth scope of 'R^2' ought to be somewhere in the range of 0.8 and 1 [19]. The value of 'R^2' indicates the nearness of the mathematical model representing the yield response. The experimental results and the deviations are given in Table 7 and the plot of the deviation is shown in Figure 10.

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Table 5: Experimental results

Expt. run	Wheel Grit Size	Work speed	Table feed, mm/rev of job	Grinding Depth of cut	Dressing feed	Dressing Depth of cut	Coolant flow	Surface Roughness					S/N Ratio
		(m/min)	(mm/rev)	(µm)	(mm/min)	(µm)	(l/min)	(µm)					
	A	B	C	D	E	F	G	Ra1	Ra2	Ra3	Ra4	Ra	
1	46	10	8	12	170	5	30	0.2361	0.2362	0.2359	0.2358	0.2360	12.5418
2	46	10	12	18	220	10	40	0.2191	0.2188	0.2192	0.2190	0.2190	13.1911
3	46	10	16	24	270	15	50	0.2242	0.2240	0.2241	0.2238	0.2240	12.9950
4	46	14	8	18	270	15	50	0.1998	0.1999	0.2002	0.2001	0.2000	13.9794
5	46	14	12	24	170	5	30	0.2281	0.2282	0.2280	0.2278	0.2280	12.8413
6	46	14	16	12	220	10	40	0.2238	0.2240	0.2241	0.2242	0.2240	12.9950
7	46	18	8	24	220	10	40	0.2302	0.2301	0.2298	0.2300	0.2300	12.7654
8	46	18	12	12	270	15	50	0.2250	0.2248	0.2252	0.2251	0.2250	12.9563
9	46	18	16	18	170	5	30	0.2481	0.2482	0.2479	0.2478	0.2480	12.1110
10	60	10	8	12	170	10	50	0.2378	0.2380	0.2381	0.2382	0.2380	12.4685
11	60	10	12	18	220	15	30	0.2402	0.2401	0.2400	0.2398	0.2400	12.3958
12	60	10	16	24	270	5	40	0.2318	0.2319	0.2322	0.2321	0.2320	12.6902
13	60	14	8	18	270	5	40	0.2561	0.2558	0.2562	0.2560	0.2560	11.8352
14	60	14	12	24	170	10	50	0.2438	0.2440	0.2441	0.2442	0.2440	12.2522
15	60	14	16	12	220	15	30	0.2583	0.2581	0.2578	0.2578	0.2580	11.7676
16	60	18	8	24	220	15	30	0.2460	0.2461	0.2455	0.2464	0.2460	12.1813
17	60	18	12	12	270	5	40	0.2602	0.2604	0.2595	0.2599	0.2600	11.7005
18	60	18	16	18	170	10	50	0.2548	0.2551	0.2552	0.2550	0.2550	11.8692
19	80	10	8	12	170	15	40	0.2641	0.2642	0.2638	0.2639	0.2640	11.5679
20	80	10	12	18	220	5	50	0.2649	0.2648	0.2652	0.2651	0.2650	11.5351
21	80	10	16	24	270	10	30	0.2722	0.2721	0.2719	0.2718	0.2720	11.3086
22	80	14	8	18	270	10	30	0.2658	0.2659	0.2661	0.2662	0.2660	11.5024

23	80	14	12	24	170	15	40	0.2751	0.2752	0.2748	0.2750	0.2750	11.2133
24	80	14	16	12	220	5	50	0.2690	0.2688	0.2691	0.2692	0.2690	11.4050
25	80	18	8	24	220	5	50	0.2803	0.2798	0.2801	0.2799	0.2800	11.0568
26	80	18	12	12	270	10	30	0.2708	0.2709	0.2712	0.2711	0.2710	11.3406
27	80	18	16	18	170	15	40	0.2852	0.2851	0.2848	0.2850	0.2850	10.9031

Table 6: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
A	1	0.009440	78.53%	0.003278	0.003278	140.96	0.0001
B	1	0.000672	5.59%	0.000515	0.000515	22.14	0.0050
C	1	0.000144	1.20%	0.000070	0.000070	3.00	0.1440
D	1	0.000011	0.09%	0.000003	0.000003	0.12	0.7400
E	1	0.000249	2.07%	0.000061	0.000061	2.63	0.1660
F	1	0.000181	1.50%	0.000190	0.000190	8.17	0.0350
G	1	0.000235	1.95%	0.000154	0.000154	6.62	0.0500
A*B	1	0.000006	0.05%	0.000127	0.000127	5.46	0.0670
A*C	1	0.000012	0.10%	0.000000	0.000000	0.00	0.9920
A*D	1	0.000080	0.67%	0.000000	0.000000	0.01	0.9400
A*E	1	0.000056	0.47%	0.000045	0.000045	1.95	0.2210
A*F	1	0.000000	0.00%	0.000047	0.000047	2.00	0.2160
B*C	1	0.000001	0.01%	0.000000	0.000000	0.00	0.9460
B*D	1	0.000004	0.03%	0.000011	0.000011	0.48	0.5210
B*F	1	0.000089	0.74%	0.000001	0.000001	0.03	0.8700
B*G	1	0.000003	0.03%	0.000000	0.000000	0.00	0.9570
C*D	1	0.000071	0.59%	0.000104	0.000104	4.49	0.0880
C*F	1	0.000543	4.51%	0.000392	0.000392	16.85	0.0090
C*G	1	0.000069	0.57%	0.000000	0.000000	0.00	0.9650
D*F	1	0.000000	0.001%	0.000000	0.000000	0.02	0.9000
E*F	1	0.000039	0.33%	0.000039	0.000039	1.69	0.2500
Error	5	0.000116	0.97%	0.000116	0.000023		
Total	26	0.012021	100.00%				
$R^2=0.99$				$R^2(Adj)=0.95$			

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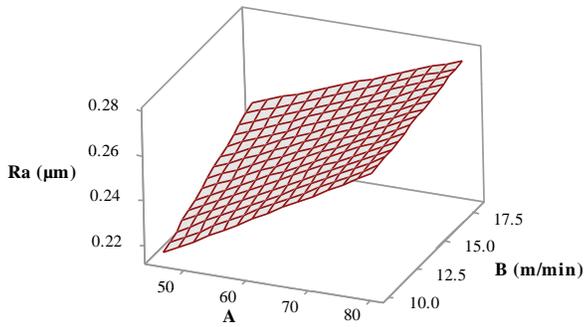

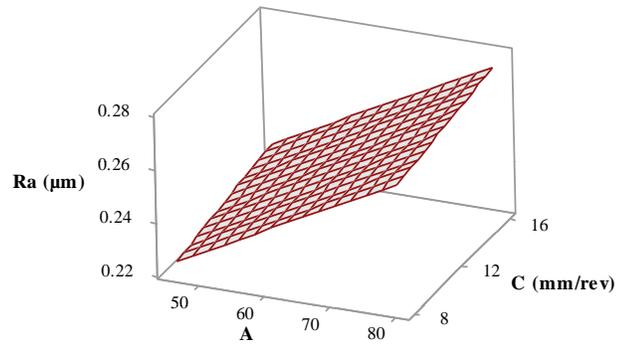**Figure 4: Surface plot of 'Ra' versus wheel grit size and work speed**

Figure 5: Surface plot of 'Ra' versus wheel grit size and table feed
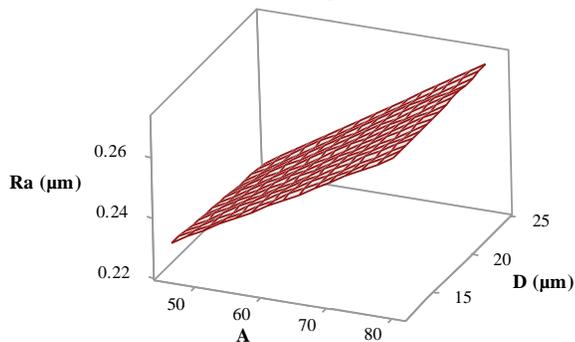

Figure 6: Surface plot of 'Ra' versus wheel grit size and grinding depth of cut
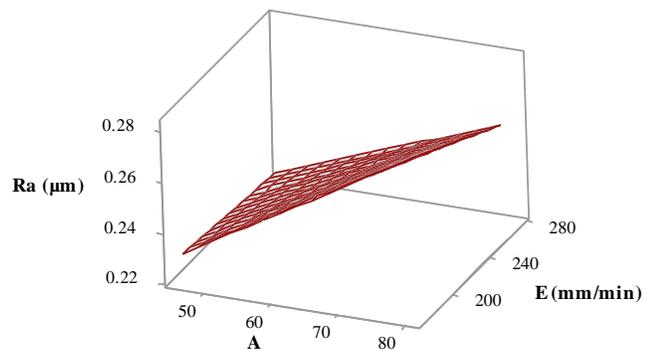

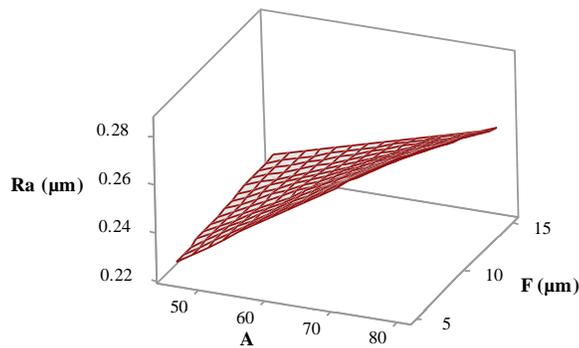**Figure 7: Surface plot of 'Ra' versus wheel grit size and dressing feed**

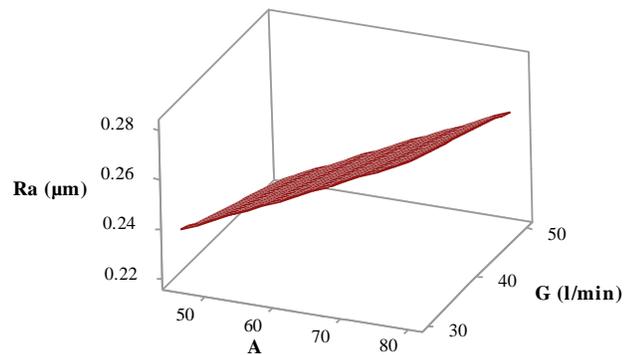**Figure 8: Surface plot of 'Ra' versus wheel grit size and dressing depth of cut**

Figure 9: Surface plot of 'Ra' versus wheel grit size and coolant flow rate

Table 7: Experimental results and deviations

Expt. Run	Wheel Grit Size	Work speed	Table feed, mm/rev of job	Grinding Depth of cut	Dressing feed	Dressing Depth of cut	Coolant flow	Surface Roughness		
		(m/min)	(mm/rev)	(µm)	(mm/min)	(µm)	(l/min)	(µm)		
	A	B	C	D	E	F	G	Actual, Ra	Predicted, Ra	Deviation %
1	46	10	8	12	170	5	30	0.2360	0.2383	0.9718
2	46	10	12	18	220	10	40	0.2190	0.2183	0.3505
3	46	10	16	24	270	15	50	0.2240	0.2274	1.5050

4	46	14	8	18	270	15	50	0.2000	0.2061	2.9786
5	46	14	12	24	170	5	30	0.2280	0.2321	1.7371
6	46	14	16	12	220	10	40	0.2240	0.2313	3.1536
7	46	18	8	24	220	10	40	0.2300	0.2351	2.1537
8	46	18	12	12	270	15	50	0.2250	0.2271	0.9050
9	46	18	16	18	170	5	30	0.2480	0.2480	0.0177
10	60	10	8	12	170	10	50	0.2380	0.2417	1.5115
11	60	10	12	18	220	15	30	0.2400	0.2469	2.7877
12	60	10	16	24	270	5	40	0.2320	0.2367	1.9906
13	60	14	8	18	270	5	40	0.2560	0.2576	0.6284
14	60	14	12	24	170	10	50	0.2440	0.2442	0.0577
15	60	14	16	12	220	15	30	0.2580	0.2593	0.4906
16	60	18	8	24	220	15	30	0.2460	0.2488	1.1429
17	60	18	12	12	270	5	40	0.2600	0.2666	2.4785
18	60	18	16	18	170	10	50	0.2550	0.2591	1.5841
19	80	10	8	12	170	15	40	0.2640	0.2675	1.3040
20	80	10	12	18	220	5	50	0.2650	0.2731	2.9759
21	80	10	16	24	270	10	30	0.2720	0.2772	1.8766
22	80	14	8	18	270	10	30	0.2660	0.2725	2.3688
23	80	14	12	24	170	15	40	0.2750	0.2783	1.1825
24	80	14	16	12	220	5	50	0.2690	0.2713	0.8502
25	80	18	8	24	220	5	50	0.2800	0.2853	1.8365
26	80	18	12	12	270	10	30	0.2710	0.2788	2.7900
27	80	18	16	18	170	15	40	0.2850	0.2906	1.9319

The average deviation between predicted and actual experimental response values was found to be 1.61%. Since error percentage is lesser than 5%, the mathematical model illustrated in equation (2) could be used for predicting surface roughness for various machining conditions.
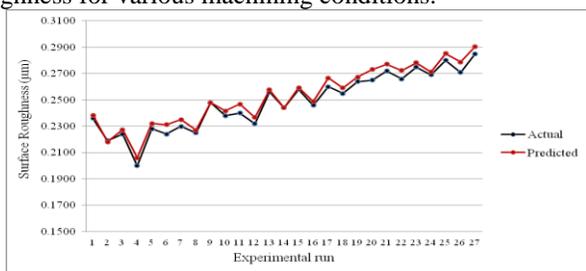

Figure 10: Plot of predicted and actual experimental response values

A.4   Response curves

Response curves are a graphical depiction of the adjustment in execution uniqueness for the variety in factor levels. Figure 11 outlines the response graph for seven variables and three levels. From the graph, the pinnacle focuses were picked as the ideal levels of machining factors i.e. wheel grit size at first level, the work speed at first level, table feed mm/rev of job at first level, grinding depth of cut at second level, dressing feed at the third level, dressing depth of cut at the third level and coolant flow at the third level.

The surface roughness of the machined steel alloy components increases with an increase in all the machining factors. When the EN 353 cylindrical steel alloy components were machined at maximum grit size, rough surface a sign of poor quality components were obtained and at the minimum grit size 46, it was observed that the roughness of the machined component was also minimum. At higher table feed and work speed, more material has to be removed which resulted in increased cutting forces on the tool and concurrently increased the energy required to machine the steel alloy components. These increased cutting forces diminished the surface quality of the steel alloy components.
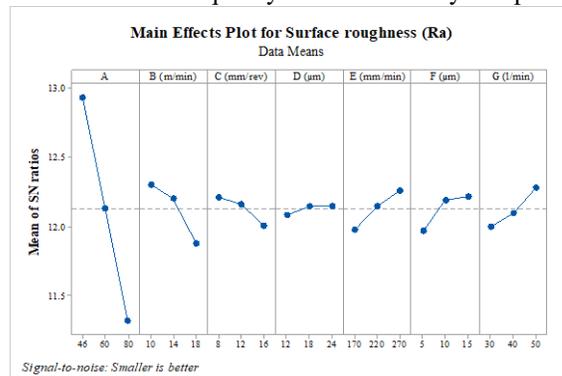

Figure 11: Response graph

A.5   Confirmation test: The confirmation test was directed at the ideal levels of machining parameters and the outcome is given in Table 8.
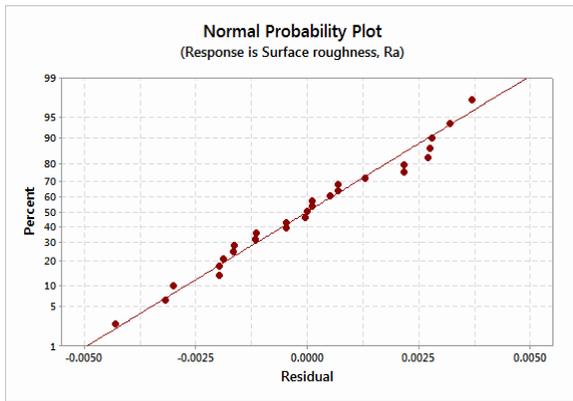
Figure 12: Normal probability plot of residuals for surface roughness data

Table 8: Confirmation test

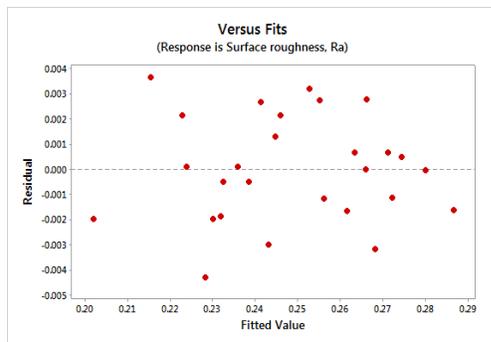| Factors							Surface roughness (Ra) in μm		Deviation %
Wheel Grit Size	Work speed	Table feed, mm/rev of job	Grinding Depth of cut	Dressing feed	Dressing Depth of cut	Coolant flow	Experimented	Predicted	
A	B (m/min)	C (mm/rev)	D (μm)	E (mm/min)	F (μm)	G (l/min)			
46	14	12	12	220	5	50	0.1798	0.1864	3.5449

Figure 13: The plot of residuals vs. fitted surface roughness values

The competence of the prediction model has been explored by the assessment of residuals. The residuals, which are the distinction between the actual response and the predicted response, are inspected utilizing normal probability plots of the residuals and the plots of the residuals versus the predicted response. On the off chance that the model is satisfactory, the focuses on the normal probability plots of the residuals should shape a straight line. Then again, the plots of the residuals versus the predicted response ought to be structureless, that is, they ought to contain no conspicuous example. The typical normal probability plots of the residuals and the plots of the residuals versus the predicted response for the surface roughness esteem have appeared in Figure 12 and Figure 13. It uncovered that the residuals, for the most part, fall on a straight line suggesting that the blunders are circulated ordinarily. This implies that the model proposed is adequate and there is no reason to suspect any violation of the constant variance assumption.

IV. CONCLUSION

In this background, the study reported in this paper was the surface roughness test conducted during cylindrical grinding operation of EN 353 steel with a white Aluminium oxide grinding wheel of three grit sizes in flooded coolant condition. The following conclusions were drawn out from the present examination;

i) From ANOVA, it is evident that wheel grit size impacts more on the surface roughness, trailed by the work speed, dressing feed, coolant flow, dressing depth of cut, table feed mm/rev of job and grinding depth of cut, This is harmonizing with the current hypotheses of machining.

ii) The interaction effect of grinding wheel grit size with other machining factors on surface roughness was studied and plotted.

iii) A generalized mathematical model was developed through regression analysis using Minitab statistical software for the mean surface roughness. From the equation the mean surface roughness value could be calculated if the factors namely wheel grit size, the work speed, table feed mm/rev of job, grinding depth of cut, dressing feed, dressing depth of cut and coolant flow are known.

iv) The mathematical models obtained for surface roughness was verified with the actual values and an average variation of 1.61% was observed in the case of surface roughness.

v) From the experimentation it is clear that, wheel grit size at first level, the work speed at first level, table feed mm/rev of job at first level, grinding depth of cut at second level, dressing feed at the third level, dressing depth of cut at the third level and coolant flow at the third level yielded minimum surface roughness, which is the sign of better quality machined components.

vi) The optimum grinding condition found in this research work could be used when EN 353 steel alloy is used for the production of grinding spindle.

Nomenclature

AISI	-	American Iron and Steel Institute
ANOVA	-	analysis of variance
OA	-	orthogonal array
S/N	-	Signal to Noise
DoE	-	Design of Experiment
Ra	-	Mean surface roughness in µm
ASTM	-	American Society for Testing and Materials
^{0}C	-	Degree Celsius
cSt	-	centiStokes
m/min	-	metre per minute
mm/rev	-	millimeter per revolution
µm	-	micrometre
mm/min	-	millimetre per minute
l/min	-	litre per minute
R	-	Correlation coefficient

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AUTHORS FROFILE

M.Manikandan has obtained his bachelor degree in Mechanical Engineering from Periyar University and Master Degree in Engineering Design from Anna University. Currently he is working for his research in the field of machining in Karpagam Academy of Higher Education as a research scholar. His area of interest includes machining of heat treated steel and parameter optimization.

Dr. S. Prabagaran has completed his Diploma in Mechanical Engineering from DOTE - Tamilnadu in the year 1979. He started his career at Lakshmi Machine Works Limited (LMW) from 1979 as Supervisor and grew up as a Manager, having 31 years of industrial experience at LMW. He completed his Undergraduate Degree B.E in Mechanical Engineering from Bharathiyar University at Govt. College of Technology, Coimbatore in the year 1986. He completed his Post graduate Degree M.E in Machine Tool Engineering from Bharathiyar University at P.S.G.College of Technology, Coimbatore in the year 1988. He obtained his Master's Degree M.S in Manufacturing Management from BITS – Pilani, in the year 2002. He was awarded with Ph.D in Manufacturing (Research work in Metal Matrix Hybrid Composites) by Karpagam University in the year 2015. He started his Teaching career from 4.1.2010 at Karpagam University, Coimbatore as Assistant Professor in Mechanical Engineering Dept. and now working as Professor in Mechanical Engineering. He has authored for 6 Technical articles (manufacturing) which are published in reputed international journals and co – authored for 25 Technical articles (manufacturing) which are published in reputed international journals. He has co- authored a text book on "A Smart LEAN practice in SME" published by "Lambert Academic Publishing", Germany. He is an approved Technical and Management article reviewer of the international Journal "Advances in Science, Technology and Engineering Systems Journal (ASTESJ)".

N.M.Sivaram received his BE degree in Production Engineering from PSG College of Technology, Coimbatore in 2008; MTech degree in Industrial Safety Engineering from National Institute of Technology, Tiruchirappalli in 2010 and Ph.D. degree in Mechanical Engineering from Anna University, Chennai through PSG College of Technology, Coimbatore in 2014. He is currently working as Assistant Professor in the Department of Mechanical Engineering, National Institute of Technology Puducherry, Karaikal, India. He has 24 papers published in international journals. His current research interests include manufacturing engineering and industrial safety engineering.

The Effects of Cylindrical Grinding Factors in the Production of Grinding Spindle using Hardened EN353 Steel

Milon Selvam Dennison received his BTech degree in Mechanical Engineering from Bharath Institute of Higher Education and Research, Chennai, India, ME degree in Manufacturing Engineering from Anna University, India and a Ph.D. degree from Karpagam Academy of Higher Education, India in 2007, 2009 and 2018 respectively. Presently, he is doing research in the field of metal cutting fluids. He has various publications in both national and international journals. He is currently working as Senior Lecturer in the Department of Mechanical Engineering, Kampala International University, Uganda. His current research interests include manufacturing of materials, metal cutting, metal cutting fluids and machining optimisation.