NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

Statistical Study of Factors Influencing Surface Roughness of Machined Work-piece Using Split-Split Plot Design

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ARTICLE INFORMATION

Article history:
Received 25 February 2019
Revised 02 March 2019
Accepted 13 March 2019
Available online 28 March 2019

Keywords:
Surface Roughness
Split-Split Plot
Machined Tools
Work piece
Cutting Speed

ABSTRACT

Profound concern had been expressed in the past on the crafting of apposite experimental-design that can facilitate the simultaneous study of the individual and conjunctive effects of several experimental treatments incorporated in one experimental setting. This work has triumphed over this perceived difficulty by adopting the split-split plot experimental-design to the study of four treatments namely: work piece material, spindle speed, tool type and tool angle, all taken at different factor levels. Our experimental results suggest that tooling and spindle speed are critical factors that determine the degree of surface integrity of a machined work piece. The author believes that the results proposed could be useful, helpful and insightful to Machinist, Production Engineers, Quality Engineers and Meteorologists in understanding the dynamics of interplay of these factors with regard to the quality of surface finish of machined work piece.

1. Introduction

The level of surface roughness of machined work piece, often measured by tool-makers microscope, is largely influenced by the nature of the work piece material and coolant as well as the choice of process variables, for instance, cutting speed, tool-type, tool geometry, depth of cut, etc. The problem associated with understanding the response of several factors, together with the ways they interact have been extensively investigated by many researchers. This work presents a new and elaborate experimental approach to the investigation.

There is vast literature on surface topology of machined work piece. Notable among them include [1] who described the surface roughness of machined parts as one of the most important characteristic of a product quality. They noted that surface roughness appears to be the crucial factor to be considered in evaluating the quality of any product. It was deduced also that lack of good surface quality fails to satisfy one of the main technical requirements for mechanical products, while higher production cost and lower productivity of cutting operations prove influential in getting high level of surface quality. Lee and Li [2] carried out a study on the surface integrity of machined workpiece in the EDM of tungsten Carbide. Some tests such as EDM test on a tungsten carbide workpiece, EDMed surface morphology test, Surface hardness test were carried out using Charmilles Technologies Roboform 40 EDM Die-Sinking Machine, scanning electron microscope (SEM) (JEOL JSM-5600LV) with energy dispersive spectrometers and macro-hardness tester respectively. The result of the study showed no difference between the hardness of the EDMed surface and the original hardness of the workpiece for all EDM conditions. Toh [3] worked on the surface topography analysis in high speed finish milling inclined hardened steel. The study assessed the surface topography effects with regards to different cutter path orientations. Result showed that milling in a single direction vertical upward orientation produced the best workpiece surface texture. Taylor et al. [4] also characterized the effect of surface roughness and texture on fluid flow. They reviewed the past, present and future work in this area and came to a conclusion that the exact effect of roughness on fluid flow has not been completely understood but said that working estimate has been offered by a variety of authors. Suhail et al. [5] optimized cutting parameters based on surface roughness and assistance of workpiece surface temperature in turning process using two performance measures, workpiece surface temperature and surface roughness as well as employing Taguchi techniques to optimized cutting parameters. The authors also employed analysis of variance, orthogonal array and signal to noise ratio to evaluate the performance characteristics in turning operation. The result of the experiment revealed workpiece surface temperature as an effective indicator to control the cutting performance and improves the optimization process. Das et al. [6] carried out analysis of surface roughness on machining of Al-5CU Alloy in CNC Lathe Machine. Cutting speed, depth of cut and feed rate were used in the experiment as cutting parameters. Other parameters such as tool nose radius, workpiece length, workpiece diameter, and workpiece material was taken as constant. The authors employed the use of 3D profilometer during the investigation to check the effect of process parameters. Kumar and Paswan [7] investigated the effects of cutting parameters on surface roughness in hard milling of AISI H13 steel with coated carbide tools. Based on face centered cubic method, the authors employed spindle speed, feed rate, depth of cut and commercial statistical software. Analysis of the results was carried out using RSM and analysis of variance (ANOVA). The result showed that spindle speed and the feed are the two dominant factors affecting the surface roughness. Hemaid et al. [8] made experimental investigation on surface finish during turning of aluminum under dry and minimum quantity lubrication machining conditions considering feed rate, cutting speed and the coolant flow rate. It was observed that a small amount of supply of coolant at the point of cutting, largely improves the surface finish. Other researchers like Ming et al. [9] carried out experimental research on the dynamic characteristics of the cutting temperature in the process of high-speed milling. The study presented an inverse heat-transfer model considering three-dimensional transient heat conduction to calculate the heat flux and the temperature distribution on the tool–workpiece interface in the high speed milling process. The result of the experiment revealed a close agreement between the calculated temperature value and the measured temperature value of the cutting interface in high-speed milling of aluminum alloy. Dontamsetti and Fischer [10] established the effect of tool wear on surface roughness and considered the process variables affecting surface roughness. The results showed that surface roughness is significantly affected by tool wear and the interactions between tool wear and other variables like cutting speed, feed rate and nose radius. Kaewkuekool et al. [11] studied the influence factors affecting the surface roughness in stainless steel turning. The results revealed that influence factor that affects surface roughness was cutting speed, which were significantly different to surface quality at the level of .05. Osarenmwinda [12] considered the empirical model for estimating the surface roughness of machined components under various cutting speed. The author during the research developed empirical models for estimating the surface roughness of machined components under various cutting speed. Feng and Wang [13] also developed empirical models for surface roughness prediction in finish turning by considering workpiece hardness (material); feed; cutting tool point angle; depth of cut; spindle speed; and cutting time as working parameters. The values of surface roughness predicted by this model were verified with extra experiments and compared with those from some of the representative models in the literature. Cakir et al. [14] investigated the influences of the cutting parameters like the feed rate, the cutting speed and the depth of cut as well as the two-coated carbide inserts on the surface roughness in the turning process. Risbood et al. [15] predicted the surface roughness and dimensional deviation by measuring cutting forces and vibrations in turning process. The cutting speed, feed rate and depth of cut were chosen as an input and the workpiece was steel bars. It was observed that the length and the diameter of the steel bar have insignificant effect on the surface roughness compared to the cutting speed, feed rate and depth of cut.

Moreover, an impressive body of research work addresses the theory and design of experiments on the quality of surface finish of workpiece material [16]. A study by Maslenikov et al. [17] proposed a model that accounts for the isotropic surface roughness and can be used to correct data in two limiting cases. Meanwhile, machined surface quality prediction researches are conducted to analyze the surface roughness by collecting and analyzing experiment data. Again, the work by Verma et al. [18] used the Taguchi method in the end milling process to identify the variables having a major influence on surface finish. A nonparametric time series processing technique called the singular spectrum analysis was also used to model vibration signals in order to forecast surface finish in precision end milling [19]. At present, many researches focus on the prediction of surface quality using mathematical and algorithmic modeling. Such include Li et al. [20] who adopted the statistical multiple regression technique to study the effect of variation of spindle speed, feed rate, and depth of cut on surface finish in the end milling of 6061 aluminum. The regression model proposed by the authors predicted the surface roughness on the test data with an accuracy of 90.03%. Lu and Wang [21] likewise proposed a generalized model that can predict the surface roughness and burns of alumina grinding wheels during the grinding of cylindrical surfaces. Nalbant et al. [22] used Taguchi method to find the optimal cutting parameters for surface roughness in turning. The orthogonal array, the signal-to-noise ratio, and analysis of variance were employed to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. Hascahk and Caydas [23] investigated the effect and optimization of machining parameters on surface roughness and tool life in a turning operation by using the Taguchi method. The experimental studies were conducted under varying cutting speeds, feed rates, and depths of cut. The conclusions revealed that the feed rate and cutting speed were the most influential factors on the surface roughness and tool life, respectively. The surface roughness was discovered to be chiefly related to the cutting speed, whereas the axial depth of cut had the greatest effect on tool life. Ribeiro et al. [24] studied the machining process by associating the Taguchi method to optimize surface quality in a CNC end milling operation by considering the most common controllable parameters like cutting speed, feed rate and depth of cutting as well as using feed per tooth, cutting speed and radial depth of cut as control factors. Karayel [25] presented a neural network approach for the prediction and control of surface roughness in a computer numerically controlled (CNC) lathe. In this study three cutting parameters which comprised of depth of cutting, cutting speed, and feed rate were used. The results of the study were obtained and compared with actual values. Benardos and Vosniakos [26] again predicted surface roughness in CNC face milling using neural networks and Taguchi's design of experiments. Their model was developed based on cutting parameters such as spindle speed, feed rate, ratio of cutting width to cutting tool diameter, and depth of cut. Their investigations demonstrated that the depth of cut as well as feed rate influences or increases surface quality. Face milling prediction of surface roughness using genetic algorithm was carried out by [27]. The spindle speed, feed rate, depth of cut, and vibrations were used as independent input variables, while the surface roughness was used as a dependent output variable. The result point feed rate as the most effective parameter on the surface quality changes.

Mohd Zain et al. [28] predicted the surface roughness in the end milling using the artificial neural network. The authors developed the surface roughness models using cutting speed and feed rate by employing the use of factorial design of experiment integrated with regression technique. Thangavel and Selladurai [29] developed a mathematical model to study the effect of cutting parameters on the surface roughness using the response surface methodology (RSM). After the regression analysis and the variance analysis, the results established the model adequacy and showed that all the main cutting parameters employed have a significant impact on the surface roughness.

Besides, the problem of studying simultaneously the interaction of several factors that affect the surface integrity of a machined workpiece had been on-going. Many researchers have adopted different approaches. Previous researchers had devoted considerable attention to the measurement of surface roughness per se but there appears to be less emphasis on fully classifying the interplay of the factors thereof. The method proposed in this study is the use of split-split plot experimental design for handling two treatments and two blocks of which one block is subsumed in the other. The resulting experimental design presents a unique integration of response variables that requires the development of a special statistical model to handle. The aim of this study is to apply split-split plot experimental design incorporating several factors as treatments and others as blocks, and the entire matrix of data as an analytical hierarchy process in an attempt to provide statistical decision support tool for classifying the nature of complementary relationship among variables studied.

2. Methodology

2.1 Experimentation

2.1.1 Specimens

Four types of workpiece materials namely brass, copper, mild-steel and aluminum were sourced from metal scrap market located at Owode in Lagos, Nigeria. Each of four bars measuring about 20mm was cut into small cylinders of about 60mm long. Altogether 180 of such pieces were cut from several bars.

2.1.2 Equipment

Various tools namely High Speed Steel (HSS), carbide tools, cobalt were assembled thereof. Each of the three categories were ground to 10^0, 15^0 and 20^0 respectively. Centre lathe installed with 3 self-centering chuck and incorporating a variable speed drive, was employed in machining the 180 workpiece batch.

2.1.3 Experimental Method

Each of the 180 specimens was machined at a specific speed using specific tool of given rake angle. Four speed regimes namely 260, 370, 540 and 800 rpm and three angle treatments (10^0, 15^0 and 20^0) were employed. All in all, 180 experimental runs or trials were undertaken. Each of the 180 specimens were identified with inscriptional label on masking tape. Finally, the entire specimens were taken to the laboratory where the surface roughness, in the form of ridges and troughs, was examined with the aid of tool maker's microscope. Three replicates of each measurement were taken and the average computed. The response variables for the entire batch were recorded and depicted in Figures 2. Thereafter, statistical computations were undertaken and results summarized in ANOVA result format shown in Table 1. Figure 1 depicts the crafting of the abridged abstract experimental design using dot notation to represent the response variables. On the other hand, Figure 2 illustrates self-same design with response variables in each cell represented as numerical observation while Figure 3 (i-iii) represent the abridged numerical data matrix design.

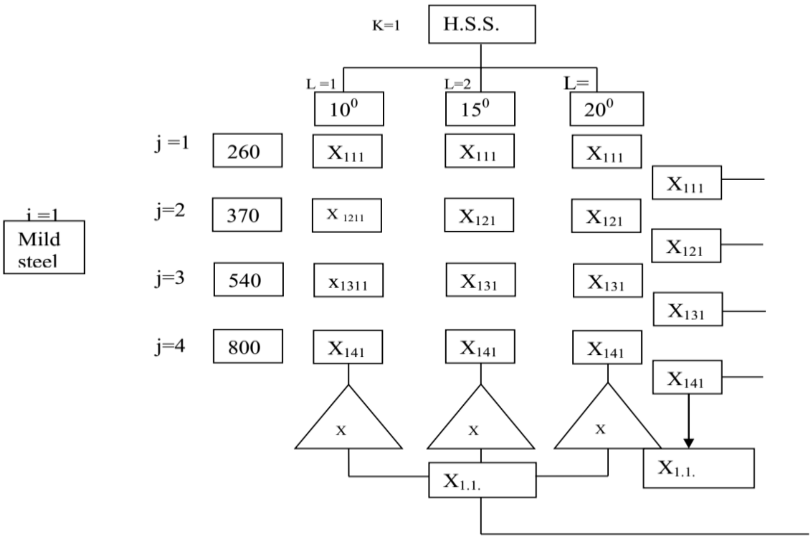


Figure.1 Abridged analytical zoomed split-split plot abstract design for one workpiece material in one tool

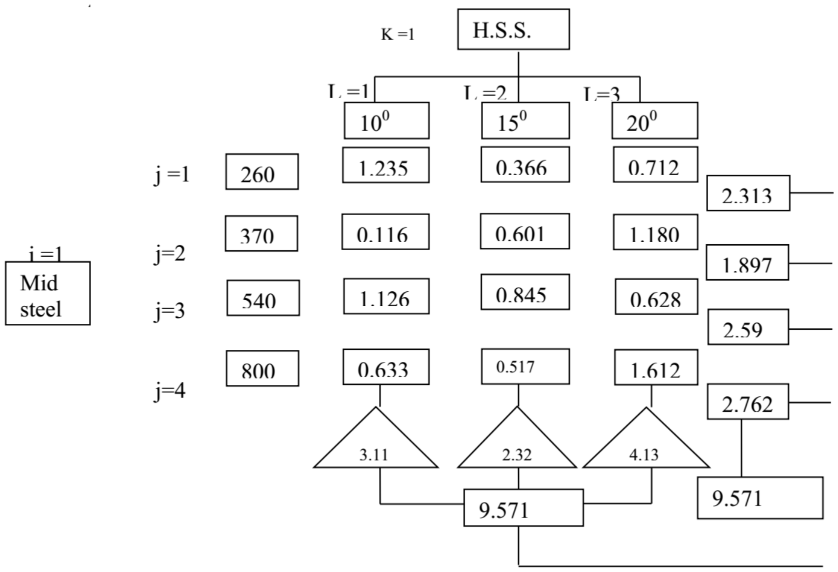
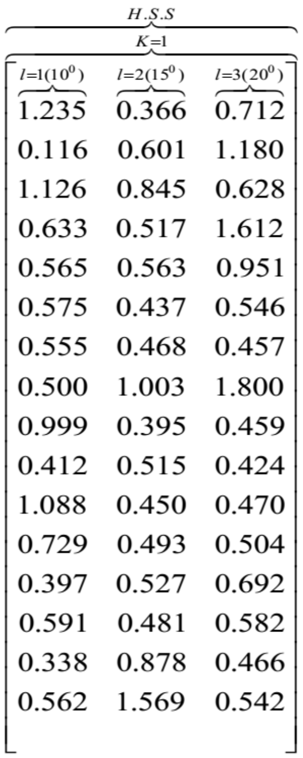
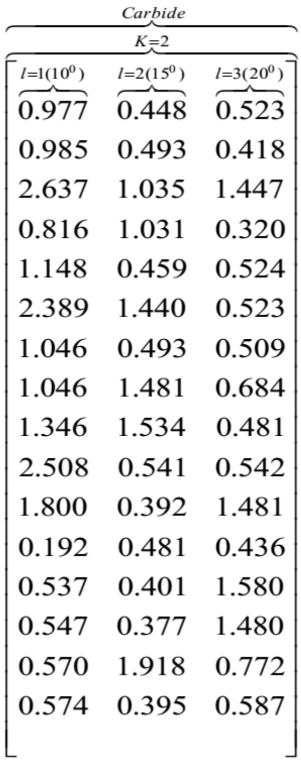


Figure 2: Abridged numerical zoomed split-split plot abstract design for one workpiece material in one tool type



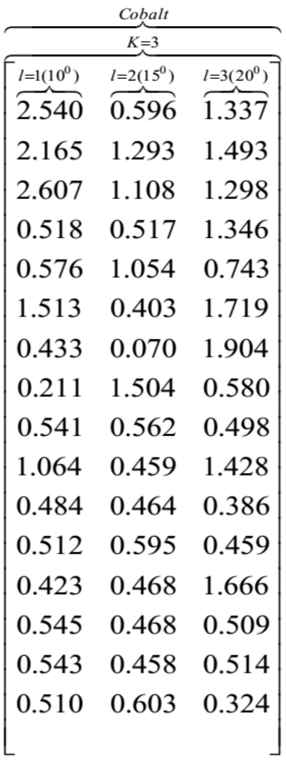
H.S.S K=1 $l=1(10^0)$	$l=2(15^0)$	$l=3(20^0)$
1.235	0.366	0.712
0.116	0.601	1.180
1.126	0.845	0.628
0.633	0.517	1.612
0.565	0.563	0.951
0.575	0.437	0.546
0.555	0.468	0.457
0.500	1.003	1.800
0.999	0.395	0.459
0.412	0.515	0.424
1.088	0.450	0.470
0.729	0.493	0.504
0.397	0.527	0.692
0.591	0.481	0.582
0.338	0.878	0.466
0.562	1.569	0.542

Figure.3(i). Data Matrix for tool typ (H.S.S)



Carbide K=2 $l=1(10^0)$	$l=2(15^0)$	$l=3(20^0)$
0.977	0.448	0.523
0.985	0.493	0.418
2.637	1.035	1.447
0.816	1.031	0.320
1.148	0.459	0.524
2.389	1.440	0.523
1.046	0.493	0.509
1.046	1.481	0.684
1.346	1.534	0.481
2.508	0.541	0.542
1.800	0.392	1.481
0.192	0.481	0.436
0.537	0.401	1.580
0.547	0.377	1.480
0.570	1.918	0.772
0.574	0.395	0.587

Figure.3(ii). Data Matrix for tool type 2 (Carbide)



Cobalt K=3 $l=1(10^0)$	$l=2(15^0)$	$l=3(20^0)$
2.540	0.596	1.337
2.165	1.293	1.493
2.607	1.108	1.298
0.518	0.517	1.346
0.576	1.054	0.743
1.513	0.403	1.719
0.433	0.070	1.904
0.211	1.504	0.580
0.541	0.562	0.498
1.064	0.459	1.428
0.484	0.464	0.386
0.512	0.595	0.459
0.423	0.468	1.666
0.545	0.468	0.509
0.543	0.458	0.514
0.510	0.603	0.324

Figure.3(iii). Data Matrix for tool type 3 (Cobalt)

The model developed for this study is depicted here under in Equation 1:

$$X_{ijkl} = \mu + \tau_i + \beta_j + \delta_l + \gamma_k + (\tau\beta)_{ij} + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\delta)_{il} + (\beta\delta)_{jl} + (\gamma\delta)_{kl} + (\tau\beta\gamma)_{ijk} + (\tau\beta\delta)_{ijl} + (\tau\gamma\delta)_{ikl} + (\beta\gamma\delta)_{jkl} + (\tau\beta\delta\gamma)_{ijkl} + \varepsilon_{(ijkl)} \begin{Bmatrix} i = 1,2,3,4 \ldots I \\ j = 1,2,3,4 \ldots J \\ k = 1,2,3 \ldots K \\ l = 1,2,3 \ldots L \end{Bmatrix} \qquad (1)$$

Where,

i = 1,2,3,4 Workpiece material (brass, copper, mild - steel and aluminum)

j = 1,2,3,4 Speed (260, 370, 540 and 800)

k = 1, 2, 3 Tools (HSS, carbide and cobalt)

l = 1, 2, 3 Tool Angle (10^0, 15^0 and 20^0)

I, J, K, L Fixed effect factor numbers

2.2 Statistical Computation

A. Total Sum of Squares

$$SS_T = \sum_{i=1}^{I=4} \sum_{j=1}^{J=4} \sum_{k=1}^{K=3} \sum_{l=1}^{L=3} X^2{}_{ijkl} - \frac{X^2_{....}}{IJKL} \qquad (2)$$

$$= \left\{ \left(1.235^2 + 0.366^2 + 0.712^2 + \ldots + 0.386^2 + 0.512^2 + 0.595^2 + 0.459^2 + \ldots + 0.772^2 + 0.468^2 + 0.878^2\right) - \frac{117.914^2}{4 \times 4 \times 3 \times 3} \right\}$$

$= 41.74$

Figure.3(ii). Data Matrix for tool type 2 (Carbide)

B. Sum of Squares for Tools (SS_A)

$$SS_A = \sum_{k=1}^{K=3} \frac{X^2_{..k.}}{IJL} - \frac{X^2_{....}}{IJKL} \qquad (3)$$

$$= \left[\left(\frac{32.559^2 + 43.344^2 + 42.011^2}{48} \right) - 96.55 \right]$$

$= 1.44$

C. Sum of Squares for the Angles (SS_B)

$$SS_B = \sum_{i=1}^{L=3} \frac{X^2_{...l}}{IJK} - \frac{X^2_{....}}{IJKL} \qquad (4)$$

$$= \left[\left(\frac{44.724^2 + 32.649^2 + 40.541^2}{4 \times 4 \times 3} \right) - 96.55 \right]$$

$= 1.57$

D. Sums of Squares for the Workpiece (SS_C)

$$SS_C = \sum_{i=1}^{I=4} \frac{X^2_{i...}}{JKL} - \frac{X^2_{....}}{IJKL} \qquad (5)$$

$$=\left[\left(\frac{37.519^2+29.872^2+26.124^2+24.399^2}{4\times3\times3}\right)-96.55\right]$$

$= 2.83$

E. *Sums of squares for speed (SS_D)*

$$SS_D = \sum_{j=1}^{J=4}\frac{X_{.j..}}{IKL} - \frac{X^2_{....}}{IJKL} \tag{6}$$

$$=\left[\left(\frac{28.823^2+31.762^2+32.138^2+25.191^2}{4\times3\times3}\right)-96.55\right]$$

$= 0.87$

F. *Tool Type × Tool Angle interaction (SS_{AB})*

$$SS_{AB} = \sum_{k=1}^{K=3}\sum_{l=1}^{L=3}\frac{X^2_{..kl}}{IJ} - \sum_{k=1}^{K=3}\frac{X^2_{..k.}}{IJL} - \sum_{l=1}^{L=3}\frac{X^2_{...l}}{IJK} + \frac{X^2_{....}}{IJKL} \tag{7}$$

$$SS_{AB} = \left[\left(\frac{10.421^2+19.118^2+15.185^2+\ldots+12.307^2+16.204^2}{4\times4}\right)-97.99-98.12+96.55\right]$$

$= 101.28 - 97.99 - 98.12 + 96.55$

$SS_{AB} = 1.72$

G. *Tool Type × Workpiece interaction (SS_{AC})*

$$SS_{AC} = \sum_{i=1}^{I=4}\sum_{k=1}^{K=3}\frac{X^2_{i.k.}}{JL} - \sum_{i=1}^{I=4}\frac{X^2_{i...}}{JKL} - \sum_{K=1}^{K=3}\frac{X^2_{..k.}}{IJL} + \frac{X^2_{....}}{IJKL} \tag{8}$$

$$=\left[\left(\frac{9.571^2+11.13^2+16.818^2+\cdots+9.738^2+7.031^2}{4\times3}\right)-99.38-97.99+96.55\right]$$

$=103.60 - 99.38 - 97.99 + 96.55$

$SS_{AC} = 2.78$

H. *Tool type × speed interaction (SS_{AD})*

$$SS_{AD} = \sum_{j=1}^{J=4}\sum_{k=1}^{K=3}\frac{X^2_{.jk.}}{IL} - \sum_{j=1}^{J=4}\frac{X^2_{.j..}}{IKL} - \sum_{k=1}^{K=3}\frac{X^2_{..k.}}{IJL} + \frac{X^2_{....}}{IJKL} \tag{9}$$

$$=\left[\left(\frac{7.861^2+6.460^2+7.769^2+\cdots+10.269^2+7.679^2}{4\times3}\right)-102.25-97.42-97.99+96.55\right]$$

$SS_{AD} = 3.39$

I. Tool angle× Workpiece Interaction (SS_{BC})

$$SS_{BC} = \sum_{i=1}^{I=4}\sum_{l=1}^{L=3}\frac{X_{i..l}^{2}}{JK} - \sum_{i=1}^{I=4}\frac{X_{i...}^{2}}{JKL} - \sum_{l=3}^{L=3}\frac{X_{...l}^{2}}{IJK} + \frac{X_{....}^{2}}{IJKL} \tag{10}$$

$$=\left[\left(\frac{16.355^2+8.85^2+12.314^2+\cdots+8.543^2+9.719^2}{4\times 3} - 99.38 - 98.12 + 96.55\right)\right]$$

$$= 103.73 - 99.38 - 98.12 + 96.55$$

SS_{BC} = 2.78

J. Tool angle × speed Interaction (SS_{BD})

$$SS_{BD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=4}\frac{X_{.j.l}^{2}}{IK} - \sum_{i=1}^{I=4}\frac{X_{.j..}^{2}}{IKL} - \sum_{j=1}^{J=4}\frac{X_{...l}^{2}}{IJK} + \frac{X_{..kl}^{2}}{IJKL} \tag{11}$$

$$=\left[\left(\frac{11.284^2+13.415^2+13.227^2+6.803^2+\cdots+9.199^2}{4\times 3} - 97.42 - 98.12 + 96.55\right)\right]$$

$$= 102.4 - 97.42 - 98.12 + 96.55$$

SS_{BD} = 3.41

K. Workpiece materials × speed Interaction (SS_{CD})

$$SS_{CD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=4}\frac{X_{ij..}^{2}}{KL} - \sum_{i=1}^{I=4}\frac{X_{i...}^{2}}{JKL} - \sum_{j=1}^{J=4}\frac{X_{.j..}^{2}}{IKL} + \frac{X_{....}^{2}}{IJKL} \tag{12}$$

$$=\left[\left(\frac{(8.734^2+8.744^2+12.731^2+\cdots+6.457^2+5.671^2)}{3\times 3} - 99.38 - 97.42 + 96.55\right)\right]$$

$$=103.89 - 99.38 - 97.42 + 96.55$$

$S\ S_{CD}$ = 3.64

L. Tool type× tool angle × Work piece interaction (SS_{ABC})

$$SS_{ABC} = \sum_{i=1}^{I=4}\sum_{k=1}^{K=3}\sum_{l=1}^{L=3}\frac{X_{i.kl}^{2}}{J} - \sum_{i=1}^{I=4}\sum_{l=1}^{L=3}\frac{X_{i.k.}^{2}}{JL} - \sum_{k=1}^{K=3}\sum_{l=1}^{L=3}\frac{X_{..kl}^{2}}{IJ} + \sum_{k=1}^{K=3}\frac{X_{..k.}^{2}}{IJL} \tag{13}$$

$$= \left[\left(\frac{(3.110^2+2.329^2+\cdots+5.846^2+2.948^2+\cdots+1.997^2+3.013^2)}{4} - 103.60 - 101.28 + 97.99\right)\right]$$

S_{ABC} = 6.13

M. Tool type × tool angle × speed interaction (SS_{ABD})

$$SS_{ABD} = \sum_{j=1}^{J=4}\sum_{k=1}^{K=3}\sum_{l=1}^{L=3}\frac{X_{.jkl}^{2}}{I} - \sum_{j=1}^{J=4}\sum_{k=1}^{K=3}\frac{X_{.jk.}^{2}}{IL} - \sum_{k=1}^{K=3}\sum_{l=1}^{L=3}\frac{X_{..kl}^{2}}{IJ} + \sum_{k=1}^{K=3}\frac{X_{..k.}^{2}}{IJL} \tag{14}$$

$$=\left[\left(\frac{3.196^2+4.008^2+4.080^2+...+2.628^2+1.751^2+...+2.027^2+2.071^2}{4}\right)-102.25-101.28+97.99\right]$$

=110.18 - 102.25 - 101.28 + 97.99

SS_{ABD} = 4.64

N. *Tool type* × *Work piece interaction* × *Speed Interaction* (SS_{ACD})

$$SS_{ACD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=4}\sum_{k=1}^{K=3}\frac{X_{ij.l}^2}{L}-\sum_{i=1}^{I=1}\sum_{j=1}^{J=4}\frac{X_{ij..}^2}{KL}-\sum_{j=1}^{J=4}\sum_{k=1}^{k=5}\frac{X_{.j.l}^2}{IL}+\sum_{j=1}^{J=4}\frac{X_{.j..}^2}{IKL} \quad (15)$$

$$=\left[\left(\frac{2.313^2+1.897^2+2.599^2+\cdots+1.522^2+1.515^2+1.437^2}{3}\right)-103.89-102.25+97.42\right]$$

SS_{ACD} = 114.2-103.89-102.25+97.42

SS_{ACD} = 5.48

O. *Tool angle* × *Work piece* × *Speed Interaction* (SS_{BCD})

$$SS_{BCD} = \sum_{i=1}^{I=4}\sum_{j=1}^{J=4}\sum_{l=1}^{L=3}\frac{X_{ij.l}^2}{K}-\sum_{i=1}^{I=3}\sum_{J=1}^{J=4}\frac{X_{ij..}^2}{K}-\sum_{J=1}^{J=4}\sum_{i=1}^{L=3}\frac{X_{ij..}^2}{IK}+\sum_{j=1}^{J=4}\frac{X_{ij..}^2}{IKL} \quad (16)$$

$$=\left[\left(\frac{4.752^2+1.410^2+\cdots+3.254^2+1.752^2+\cdots+2.567^2+1.458^2}{3}\right)-103.89-102.4+97.42\right]$$

SS_{BCD} = 114.97 - 103.89 -102.40 + 97.42

SS_{BCD} = 6.10

P. *Error sums of squares* (SS_E)

$$SS_E = SS_T - SS_A - SS_B - SS_C - SS_D - SS_{AB} - SS_{AC} - SS_{AD} - SS_{BC} - SS_{CD} - SS_{ABC} - SS_{ABD} - SS_{ACD} \quad (17)$$

SS_E = 41.74-1.44-1.57-2.83-0.87-1.72-2.78-3.39-2.78-3.64-6.13-4.64-5.48

$SS_E = 4.47$

3. Results and Discussion

The above computational data is encapsulated and depicted in Table 1.

Table 1: ANOVA Result for Surface Roughness of Machined Workpiece

Sources of Variation	**Sums of squares**	**Degrees of Freedom**	**Mean of squares**	**Fisher's ratio (F_{cal})**	**Fishers ratio (F_{tab})**	**Decision**
SS_A	1.44	K-1=2	0.72	$\frac{MS_A}{MS_B} = 0.92$	19.00	$F_{cal} < F_{tab}$ *Accept*
SS_B	1.57	L-1=2	0.78	$\frac{MS_B}{MS_{AB}} = 1.21$	6.94	$F_{cal} < F_{tab}$ *Accept*
SS_C	2.83	I-1=3	0.94	$\frac{MS_C}{MS_{AC}} = 2.04$	4.76	$F_{cal} < F_{tab}$ *Accept*
SS_D	0.87	J-1=3	0.29	$\frac{MS_D}{MS_{AD}} = 0.52$	4.76	$F_{cal} < F_{tab}$ *Accept*
SS_{AB}	1.72	(K-1)(L-1)=4	0.43	$\frac{MS_{AB}}{MS_C} = 0.46$	9.12	$F_{cal} < F_{tab}$ *Accept*
SS_{AC}	2.78	(K-1)(I-1)=6	0.46	$\frac{MS_{AC}}{MS_{BC}} = 1.00$	4.28	$F_{cal} < F_{tab}$ *Accept*
SS_{AD}	3.39	(K-1)(J-1)=6	0.56	$\frac{MS_{AD}}{MS_{BD}} = 0.98$	4.28	$F_{cal} < F_{tab}$ *Accept*
SS_{BC}	2.78	(L-1)(I-1)=6	0.46	$\frac{MS_{BC}}{MS_{ABC}} = 0.90$	3.00	$F_{cal} < F_{tab}$ *Accept*
SS_{CD}	3.64	(I-1)(J-1)=9	0.40	$\frac{MS_{CD}}{MS_{ACD}} = 1.33$	2.46	$F_{cal} < F_{tab}$ *Accept*
SS_{ABC}	6.13	(K-1)(L-1)(I-1)=12	0.51	$\frac{MS_{ABC}}{MS_D} = 1.76$	8.74	$F_{cal} < F_{tab}$ *Accept*
SS_{ABD}	4.64	(K-1)(L-1)(J-1)=12	0.39	$\frac{MS_{ABD}}{MS_{CD}} = 0.97$	3.07	$F_{cal} < F_{tab}$ *Accept*
SS_{ACD}	5.48	(K-1)(I-1)(J-1)=18	0.30	$\frac{MS_{ACD}}{MS_{BCD}} = 0.88$	2.22	$F_{cal} < F_{tab}$ *Accept*
SS_{BD}	3.41	(L-1)(J-1)=6	0.57	$\frac{MS_{BD}}{MS_{ABD}} = 1.46$	3.00	$F_{cal} < F_{tab}$ *Accept*
SS_{BCD}	6.10	(L-1)(I-1)(J-1)=18	0.34	$\frac{MS_{BCD}}{MS_E} = 2.83$	1.92	$F_{cal} > F_{tab}$ *Reject*
SS_E	4.47	(I-1)(J-1)(K-1)=36	0.12			
SS_T	41.74	IJKL-1=143				

3.1 Hypothesis Employed

3.1.1 Tool Type (A)

$H_A^{(0)}$: all $\gamma_k = 0$; the three tool specimens employed in the experiment impact similar surface roughness features under the same cutting conditions.

$H_A^{(0)}$: some $\gamma_k \neq 0$; the three tool specimens exhibit different surface roughness characteristics under the experimental conditions subjected.

3.1.2 Tool Angle (B)

$H_B^{(0)}$: all $\delta_1 = 0$; within the range of tool angles to which specimen tools were ground, no significant differential treatment is evident.

$H_B^{(1)}$: some $\delta_1 \neq 0$; differential treatment with respect to tool angles is significantly evident.

3.1.3 Nature of workpiece material (C)

$H_C^{(0)}$: all $\tau_i = 0$; the four types of workpiece specimens employed showed no significant differential effect under the cutting condition adopted.

$H_C^{(1)}$: some $\tau_i \neq 0$; surface roughness observed on the workpiece varied according to the nature of the workpiece material.

3.1.4 Speed Regime (D)

$H_D^{(0)}$: all $\beta_j = 0$; the level of surface roughness perceived on the workpiece, under different speed settings used in the experiment, are essentially the same.

$H_D^{(1)}$: some $\beta_j \neq 0$; surface roughness varied with the cutting speed.

3.1.5 (Tool Type)×(Tool Angle) interaction (AB)

$H_{AB}^{(0)}$: all $\gamma\delta_{kl} = 0$; there is no noticeable differences in the degree of surface roughness perceived on workpiece specimens turned with different tool types whose angles varied.

$H_{AB}^{(1)}$: some $\gamma\delta_{kl} \neq 0$; tool angle band tool type are interactive with each other in influencing the level of surface roughness of machined workpiece.

3.1.6 (Tool Type)×(workpiece) interaction (AC)

$H_{AC}^{(0)}$: all $\tau\gamma_{ik} = 0$; tool type and nature of workpiece material are never complementary in effecting the quality of surface roughness.

$H_{AC}^{(1)}$: some $\tau\gamma_{ik} \neq 0$; the type of tool employed and the nature of workpiece material being machined interact to effect the quality of surface roughness of machined workpiece.

3.1.7 (Tool Type) × (Speed) interaction (AD)

$H_{AD}^{(0)}$: all $\beta\gamma_{jk} = 0$; speed regime employed never operate in association with tool type to effect the degree of surface roughness of machined workpiece.

$H_{AD}^{(1)}$: some $\beta\gamma_{jk} \neq 0$; covariation of turning speed and tool type produces differential effect with respect to the quality of surface integrity of machine workpiece.

3.1.8 (Tool Angle)×(Workpiece) interaction (BC)

$H_{BC}^{(0)}$: all $\tau\delta_{il} = 0$; variation of workpiece material conjoining with tool angle variation are not interactive with regard to the way they influence workpiece surface roughness.

$H_{BC}^{(1)}$: some $\tau\delta_{il} \neq 0$; covariation of workpiece material with tool angle produces differential treatment.

3.1.9 (Tool Angle) × (Speed) interaction (BD)

$H_{BD}^{(0)}$: all $\beta\delta_{jl} = 0$; turning speed does not vary with tool angle to produce differential treatment.

$H_{BD}^{(1)}$: some $\beta\delta_{jl} \neq 0$; turning speed covary with workpiece material to produce differential effect.

3.1.10 (Speed) × (Workpiece) (CD)

$H_{CD}^{(0)}$: all $\tau\beta_{ij} = 0$; the spindle speed does not conjunct with the nature of workpiece to influence the quality of surface integrity.

$H_{CD}^{(1)}$: some $\tau\beta_{ij} \neq 0$; speed covary with workpiece material to produce differential effect.

3.1.11 (Tool Type) × (Tool Angle) × (Workpiece) Interaction (ABC)

$H_{ABC}^{(0)}$: all $\tau\gamma\delta_{ikl} = 0$; the interactive effect of tool type , tool angle and work piece is not noticeable.

$H_{ABC}^{(1)}$: some $\tau\gamma\delta_{ikl} \neq 0$; tool type, tool angle and workpiece material work in association to influence the quality of surface machined work.

3.1.12 (Tool Type) × (Workpiece) × (Speed) Interaction (ACD)

$H_{ACD}^{(0)}$: all $\tau\beta\gamma_{ijk} = 0$; tool type, workpiece material and speed are not interactive in the way they influence the quality of surface roughness.

$H_{ACD}^{(1)}$: some $\tau\beta\gamma_{ijk} \neq 0$; tool type, workpiece material and speed do not cojoin in the way they influence the quality of surface roughness.

3.1.13 (Tool Angle) × (Workpiece) × (Speed) Interaction (BCD)

$H_{BCD}^{(0)}$: all $\tau\beta\delta_{ijl} = 0$; tool angle, work piece material and turning speed do not work in combination to influence the level of surface quality of machined workpiece.

$H_{BCD}^{(1)}$: some $\tau\beta\delta_{ijl} \neq 0$; tool angle, workpiece material and turning speed are interactive in influencing the quality of surface roughness.

3.1.14 (Speed) × (Tool Type) × (Tool Angle) Interaction (ABD)

$H_{ABD}^{(0)}$: all $\beta\gamma\delta_{ikl} = 0$; covariation of speed, tool type and tool angle does not produce differential treatment with respect to degree of surface roughness for machined workpiece.

$H_{ABD}^{(1)}$: some $\beta\gamma\delta_{ikl} \neq 0$; turning speed, tool type and tool angle covary to produce differential treatment.

3.2 Statistical Inferences

Our decisions, based on the decision column of Table 1, are as follows: Our experimental data do not furnish preponderance evidence for us to reject all null hypothesis, except 2, 10, and 13, i.e $h_b^{(0)}$, $h_{cd}^{(0)}$ and $h_{abd}^{(0)}$. The three hypothesis thereof were accepted at a significant level of $\alpha = 0.01$.

Our conclusion therefore is that:

a. Tool geometry such as variation of rake angles directly influences the degree of surface roughness.

b. Workpiece material and speed regime interaction is very influential in the way both conjunctively affect the surface quality of a machined work piece.

c. The type of tool employed, the tool geometry as well as the speed regime adopted all conjunctively interacts with one another to affect the degree of surface quality of a machined workpiece material.

Thus, our fundamental outcome in this study is that tooling and spindle speed are crucial factors that determine the quality of surface fineness of a machined workpiece.

The split-split plot experimental design employed in this study has clearly described the nature and degree of correlation among several treatments and blocks considered. The authors propose that tool angle particularly the rake angle is a principal factor that influences the workpiece surface finish. The author also professes that there is strong correlation between tool type, tool angle, speed and workpiece material in the manner they affect surface roughness of a machined workpiece. Furthermore, the model is able to state the particular combination of these factors that give rise to certain degree of surface roughness. It is obvious from the preceding analysis that the split-split plot experimental design is a robust statistical model that wields the profound capacity to handle both individual and collective effect of several factors simultaneously in attempt to ascertain their various effects on the quality of surface finish of a machined workpiece.

4. Conclusion

This paper has been able to apply split-split plot experimental design that incorporated three process variables and workpiece material factor in one experimental setting in order to understand the dynamics of the mutual interaction of the aforementioned factors in influencing the surface quality of machined workpiece. It has been identified that tool geometry per se is a crucial factor. Moreover, tool geometry, tool material and spindle speed mutually act to affect the degree of surface roughness of a machined workpiece.

These results further suggest that speed and workpiece material jointly play crucial role in the determination of the degree of surface roughness of a machined workpiece.

Nomenclature

×	This is an operation indicating interaction between the blocks and the treatments.
A	Tool type
B	Tool angle
C :	Workpiece Material
D :	Speed
μ	Overall population mean
α_i	Model block parameter for workpiece material
α	Confidence level
β_j	Model treatment parameter for speed
γ_k	Model treatment parameter for tool type
τ_l	Model treatment parameter for tool angle
$\varepsilon_{(ijkl)}$	Error component
SS_E	Sum of squares for error
SS_T	Sum of squares for total
SS_A	Sum of squares for tool type
SS_B	Sum of squares for tool angle
SS_C	Sum of squares for workpiece
SS_D	Sum of squares for speed
SS_{AB}	Sum of squares for tool type and tool angle interaction
SS_{AC}	Sum of squares for tool type and workpiece interaction
SS_{AD}	Sum of squares for tool type and speed interaction
SS_{BC}	Sum of squares for tool angle and workpiece interaction
SS_{BD}	Sum of squares for tool angle and speed interaction
SS_{CD}	Sum of squares for workpiece and speed interaction
SS_{ABC}	Sum of squares for tool type, tool angle and workpiece interaction
SS_{ABD}	Sum of squares for tool type, tool angle and speed interaction
SS_{ACD}	Sum of squares for tool type, workpiece and speed interaction
SS_{BCD}	Sum of squares for tool angle, workpiece and speed interaction
$Error$	Discrepancy or deviation from mean value
F_{cal}	Fisher's ratio (calculated value)
F_{tab}	Fisher's ratio (tabular value)
H_0, H_1	Null, alternative hypothesis

X_{ijkl} Response variable

$X_{ijk.}, X_{ij..}, X_{i...}, X_{.jk.}, X_{.j.l}, X_{i.kl}, X_{.jkl}, X_{ij.l}, X_{i..l}, X_{..kl}, X_{.j..}, X_{..k.}, X_{...l}, X_{....}$: dot matrix notation for Summing various response variables associated with combinations of treatments, blocks and their different levels as well as replications in the context of the experimental design employed.

5. Acknowledgement

The Authors wishes to acknowledge the contributions of Mr. Nwosu O. Okechukwu during the preliminary investigations that were reported in his M.Sc Engineering Management thesis in the Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria.

6. Conflict of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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