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ANALYSIS OF THE INFLUENCE OF CUTTING TOOL GEOMETRY ON THE SURFACE TEXTURE OF A TURNED CARBON STEEL

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ABSTRACT

This study is an attempt to investigate the influence of cutting tool geometry on the surface texture of a turned cylindrical component. Centre lathes with carbide cutting tools of varying radii were used to turn the carbon steel component. Various feeds and cutting tool approach angles were used during the turning operation while Talysurf measuring instrument was used to measure the centre line average (CLA) surface roughness. Data obtained from the experiment was analysed theoretically coupled with the usage of SPSS software (version) 22.0 to obtain the mathematical relationship between the surface roughness of tool nose radius and approach angle of a cutting tool. The result showed that with constant speed and cut, surface roughness decreased when using larger tool nose radius. Based on the findings, it is recommended that tool with large nose radius and minimum approach angle should be used when finishing the turning of carbon steel.

1. INTRODUCTION

In machining process, surface finish is one of the most significant technical requirements of the customer. A reasonably good surface finish is desired to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appearance of the product. Nowadays, manufacturing industries are concerned with dimensional accuracy and surface finish of parts. In order to obtain optimal cutting parameters, manufacturing industries have depended on the use of handbook-based information which leads to decrease in productivity due to sub-optimal use of machining capability. This also results in high manufacturing cost and low product quality. Adetan *et al.* (2008) and Abiodun *et al.* (2011), developed a new tyre bead-breaking tool to eliminate the drudgery of manual bead breaking by local Nigerian tyre repair artisans. Combined effects of three cutting parameters, namely cutting speed, feed rate and depth of cut, on the six performance outputs-surface roughness parameters and cutting force components, were explored by ANOVA. Optimal cutting conditions for each performance level were established.

Conformity of geometry is one of the most significant requirement of turned components to perform its intended functions. The geometrical requirements, apart from dimensional requirements are: circularity, cylindricity, perpendicularity, etc. Since they have direct influence on the functioning of the components, the effect of the cutting parameters on them has greater significance (Tadvi *et al.*, 2011). Anoop *et al.* (2014) optimized the process parameters of surface finish for turning AISI 202 austenitic stainless steel using Taguchi approach. Nine cylindrical bars of AISI 202 of diameter 20 mm were turned to a length of 20 mm in each experiment for a constant spindle speed of 73.5 rpm on conventional lathe machine. Coolant concentration, feed rate, depth of cut and rake angle of tool were taken as the process parameters. A Taguchi orthogonal array was designed with three levels of machining parameters and analysis of ratios, response table and regression equations were made with the help of Minitab 16 software.

Khalili and Danesh, (2013), studied the influence of cutting tool geometry (angles) on morphology of flank wear land during turning of low carbon steel by using image processing techniques and Response Surface Methodology (RSM). The analysis was based on a second order model in which the flank wear (area and shape factors) is expressed as a function of three cutting tool geometry parameters (relief angle, rake angle and cutting edge angle) and the effect of tool geometry parameters and their interactive effect on flank wear land morphology were investigated. Sarkar *et al.* (2017) investigated the effects of the machining parameters on end milling of Inconel 718 using a mathematical model developed from central composite design. Silva *et al.* (2008), investigated the influence of cutting speed on cutting forces and surface roughness during dry precision turning of AISI 1045 steel using uncoated and coated cemented carbide tools. The surface roughness produced by the two cutting tools was significantly affected by cutting speedwithin the range tested. Dogra *et al.* (2011), presented a survey on variation in tool geometry i.e. tool nose radius, rake angle, groove on the rake face, variable edge geometry, wiper geometry and curvilinear edge tools and their effect on tool wear, surface roughness and surface integrity of the machined surface. Yacouv and Gurpreet (2013), Oladejo and Oriolowo (2015), analysed the effect of controlled cutting parameters namely cutting speed, feed rate, depth of cut, cutting fluid concentration and two cutting fluids with different base oils on surface roughness (Ra) of EN8 or AISI 1040 steel during turning operation. They applied design of experiments, custom design method, analysis of variance, leverage plots and desirability profiling using JMP software to optimize surface roughness during wet CNC turning operation. The analysis revealed that feed rate had the most significant effect on surface roughness (Ra) and value of surface roughness did not significantly differ for two different cutting fluids used.

This present study was designed to find out the influence of tool geometry on the surface texture of a turned component to shed light on whether cutting tool has any effect on the surface finish or not using formulated hypotheses.

2. MATERIALS AND METHODS

2.1. Experiment

Test specimens of carbon steel were prepared with dimensions 70x350 mm and used for the experiment for produce turned components. The specimens were turned on a center lathe using carbide cutting tools of nose radius 0.381 mm and 0.813 mm. Tool feed and tool approach angle were varied using a constant cut of 0.5 mm along the length of the specimen and the surface roughness was recorded using Taylor Hobson Talysurf measuring instrument.

2.2. Statistical Analysis

In order to investigate whether cutting tool has any effect on the surface finish or not, the following questions were framed:

- Does cutting tool approach angle and tool feed rate have any effect on the surface roughness of a turned component?
- Does tool nose radius have any effect on the surface roughness of a turned component?

To answer these questions, the following four null hypotheses were formulated:

- Hypothesis one: Cutting Tool approach angle has no effect on surface roughness of a turned component.
- Hypothesis two: Tool Feed rate has no effect on surface roughness of a turned component.
- Hypothesis three: Cutting Tool approach angle and Feed rate has no relationship with surface roughness when using cutting tools (nose radius 0.381 mm).
- Hypothesis four: Tool approach angle and Feed rate has no relationship with surface roughness when using cutting tools (nose radius 0.813 mm).

The hypotheses were tested using statistical package which is SPSS 22.0 version.

3. RESULTS AND DISCUSSION

Hypothesis One: Tool approach angle has no significant effect on Surface Roughness of a Turned component.

Table 1a shows that there was positive relationship between tool approach angle and surface roughness of a turned component as expressed in Equation 1.

$$\text{Surface Roughness} = 2.293 + 0.76\ (\text{Angle}) \tag{1}$$

Table1a: Model summary of hypothesis one

Model Summary

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate	Change Statistics				
					R Squared Change	F Change	df1	df2	Sig. F Change
1	0.838[a]	0.703	0.653	0.6577	0.703	14.179	1	6	0.009

a. Predictors: (Constant), Angle

Table 1b: Coefficient details of hypothesis one

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	2.293	0.512		4.474	0.004			
	Angle	0.076	0.020	0.838	3.766	0.009	0.838	0.838	0.838

a. Dependent variable: CLA

The p-value (0.009) for Angle coefficient was significant. In Table 1b, the correlation coefficient shows the degree/strength of relation (r) between tool approach angle and surface roughness of a turned component reveals to be 0.838. This indicated strong positive relationship. The R^2 value of 0.703 showed that the obtained model could explain 70.3% of the relationship between the tool approach angle and surface roughness of a turned component.

Hypothesis Two: Feed rate has no significant effect on surface roughness.
Table 2a shows that there was positive relationship between feed rate and surface roughness of a turned component.

$$\text{Surface Roughness} = 0.727 + 12.286\,(\text{feed rate}) \tag{2}$$

The p-value (0.000) for feed rate was significant, the correlation coefficient showed the degree/strength of relation (r) between feed rate and surface roughness of a turned component and was obtained to be 0.985. This indicated approximately perfect positive relationship. The R^2 value of 0.970 showed that the obtained model could explain 97.0% of the relationship between the feed rate and surface roughness of a turned component.

Table 2a: Model Summary of hypothesis two

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate	Change Statistics				
					R Squared Change	F Change	df1	df2	Sig. F Change
1	0.985[a]	0.970	0.965	0.2549	0.970	196.201	1	6	0.000

a. Predictors: (Constant), Feed rate

Table 2b: Coefficient details of hypothesis two

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	0.727	0.183		3.963	0.007			
	Feed rate	12.286	0.877	0.985	14.007	0.000	0.985	0.985	0.985

a. Dependent variable: CTNR_813

Hypothesis Three: Tools approach angle and feed rate has no significant relationship with Surface roughness with radius 0.381.
Table 3a shows that there was positive relationship between feed rate and surface roughness of a turned component. Coefficient details in Table 3b revealed that:

$$\text{Surface Roughness (radius nose 0.381mm)} = 1.726 + 10.01(\text{feed rate}) + 0.053\,(\text{Angle}) \tag{3}$$

The R^2 value of 0.942 showed that the obtained model could explain 94.2% of the relationship among the feed rate, tool approach angle and surface roughness (nose radius of 0.381 mm) of a turned component.

Table 3a: Model summary of hypothesis three

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate	Change Statistics				
					R Squared Change	F Change	df1	df2	Sig. F Change
1	0.971[a]	0.942	0.919	0.5147	0.942	40.577	2	5	0.001

a. Predictors: (Constant), Angle, Feed rate

Table 3b: Coefficient details of hypothesis three

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	1.726	0.551		3.132	0.026			
	Feed rate	10.010	19.893	0.609	0.503	0.636	0.970	0.220	0.054
	Angle	0.053	0.178	0.362	0.299	0.777	0.969	0.133	0.032

a. Dependent variable: CTNR_381

Hypothesis Four: Tools approach angle and Feed rate has no significant relationship with Surface roughness with radius 0.813 mm.

Table 4a shows that there is positive relationship between feed rate and surface roughness of a turned component. Coefficient details in Table 4b shows that

$$\text{Surface Roughness (radius nose 0.813 mm)} = 0.861 + 18.83(\text{feed rate}) - 0.059\ (\text{Angle}) \quad (4)$$

The R^2 value of 0.973 showed that the obtained model could explain 97.3% of the relationship among the feed rate, tool approach angle and surface roughness (nose radius of 0.813 mm) of a turned component.

Table 4a: Model summary of hypothesis four

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate	Change Statistics				
					R Squared Change	F Change	df1	df2	Sig. F Change
1	0.986[a]	0.973	0.962	0.2687	0.973	88.483	2	5	0.000

a. Predictors: (Constant), Angle, Feed Rate

Table 4b: Coefficient details of hypothesis four

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	0.861	0.288		2.993	0.030			
	Feed rate	18.825	10.386	1.509	1.812	0.130	0.985	0.630	0.134
	Angle	-0.059	0.093	-0.526	-0.632	0.555	0.977	-0.272	-0.047

a. Dependent variable: CTNR_831

Using Pearson correlation coefficient in Table 5, approach angle was significantly related to surface roughness with R = 0.838 and the feed rate was significantly related to surface roughness (nose radius 0.813 mm) with R = 0.97. Figure 1 revealed that roughness increased from 1.6 µm to 5 µm when approach angle increased from 5^o to 40^o. Figure 2 shows that roughness increased from 1.4 µm to 4.7 µm, as feed rate increases. Figure 3 shows that roughness increased from 1.6 µm to 6.6 µm as feed rate increased from 0.031 mm/rev to 0.325 mm/rev when 0.381 mm tool nose radius was used, and the roughness increased from 1.0 µm to 4.4 µm when 0.813 mm tool nose radius was used. This revealed that surface roughness decreases with larger cutting tool nose radius.

Table 5: Correlation analysis of the model

		Angle	Feed Rate	CTNR_381	CTNR_813	CLA
Angle	Pearson Correlation	1	0.996**	0.969**	0.977**	0.838**
	Sig. (2-tailed)		0.000	0.000	0.000	0.009
Feed_Rate	Pearson Correlation	0.996**	1	0.970**	0.985**	0.822*
	Sig. (2-tailed)	0.000		0.000	0.000	0.012
CTNR_381	Pearson Correlation	0.969**	0.970**	1	0.942**	0.887**
	Sig. (2-tailed)	0.000	0.000		0.000	0.003
CTNR_813	Pearson Correlation	0.977**	0.985**	0.942**	1	0.760*
	Sig. (2-tailed)	0.000	0.000	0.000		0.028
CLA	Pearson Correlation	0.838**	0.822*	0.887**	0.760*	1
	Sig. (2-tailed)	0.009	0.012	0.003	0.028	

**Correlation is significant at the 0.01 level (2tailed)
*Correlation is significant at the 0.05 level (2-tailed)

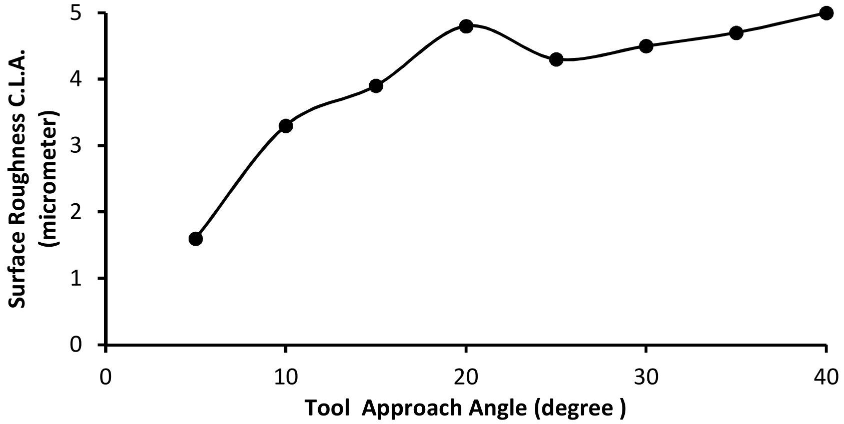

Figure 1: Relationship between tools approach angle with surface roughness

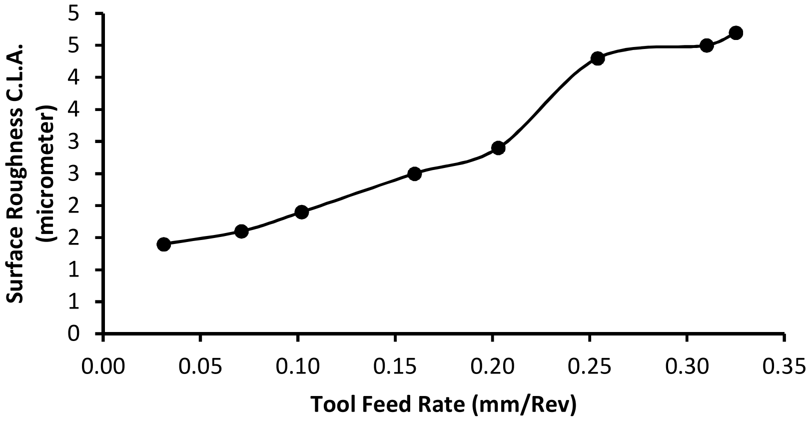

Figure 2: Relationship between Surface Roughness C.L.A. and Tool feed rate

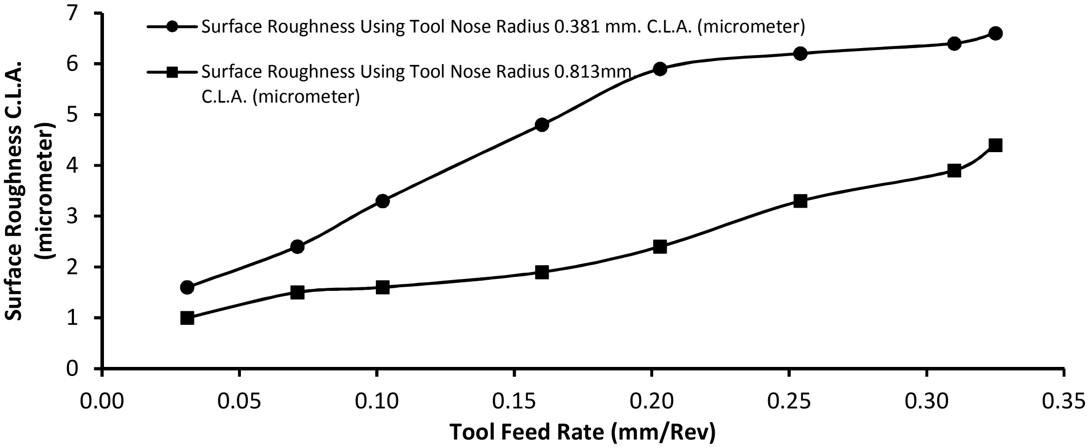

Figure 3: Effect of variation in cutting tool

4. CONCLUSION

The developed models are reasonably accurate and can be used for prediction within limits. Based on the findings, it is recommended that cutting tool approach angle must be kept to a minimum when turning steel component for better surface finish. Surface roughness of a turned component increased as cutting tool approach angle increased, and increase in approach angle increased vibration and charter on the component. In the same vein, roughness decreased as tool nose radius increased because increase in nose radius improved polishing effect on the work surface and hence improved surface finish.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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