Effect of Rake Angle on Surface Roughness in CNC Turning

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Abstract

The work and study presented in this paper aims to investigate the effect of rake angle on surface roughness in CNC turning of Aluminium (6061) with keeping other machining parameters such as cutting speed, feed rate and depth of cut as constant. Three positive rake angled tools selected to study and analyze the effect of cutting conditions on surface roughness. Design of experiments were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance to find minimum surface roughness. It was observed that the surface roughness decreases with increase in rake angle.

1. Introduction

Out of all the surface condition criteria, Ra and Rt (expressed in µm) are often used to characterize the roughness of machined surfaces.

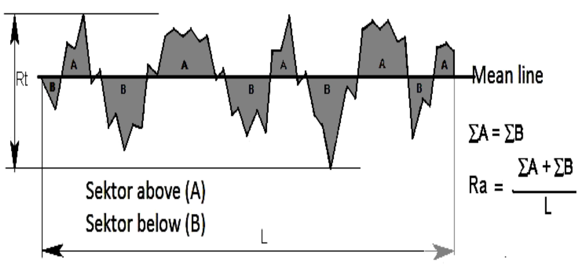

Fig: 1. Schematic of parameter definition used to compute the mean arithmetic deviation (*Ra*) and total roughness (*Rt*) (*H. Yanda et.al*, 2010)

Rt is total roughness (maximum depth or amplitude of the roughness), and *Ra* is arithmetic roughness (mean arithmetic deviation from the mean line of the roughness) as Ra = (∑A + ∑B) / L. (*H Yanda et.al.* 2010).

Definition of the mean line is $\Sigma A = \Sigma B$ as shown in Figure 1. Surface condition is being determined by several factors:

- Cutting parameters (cutting speed, feed)
- Tool geometry (angle and sharpness of the cutting edge, corner radius, etc.)
- The material the cutting tool
- The forming of chips, cutting forces, etc.

Most of automotive components are manufactured using a conventional machining process, such as turning, drilling, milling, shaping and planning, etc. Aluminium (6061) is widely used for producing automotive components by turning process. This study aims to investigate the effect of rake angle on surface roughness in CNC turning of Aluminium (6061) with keeping other machining parameters such as cutting speed, feed rate and depth of cut as constant.

Taguchi's parametric design is the effective tool for robust design it offers a simple and systematic qualitative optimal design to a relatively low cost. The Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments. In this paper Taguchi's approach is used to analyze the effect of rake angle on Surface Roughness of Aluminium 6061 work material while turning with the cutting tool which was prepared with three positive Rake angles 16^0, 18^0 and 20^0 to obtain an optimal setting of these parameters that may result in good surface finish.

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

2. Experiment Set Up

The CNC turning machine consists of the machine unit with a three jaw independent chuck, a computer numerically controlled tool slide.

After deciding the machining zero at a certain point the command is given in the form of a part program.

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Table: 1. Description of CNC Machine

	Description	Unit	Size
Capacity	Between centre length	mm	425
	Maximum machining dia	mm	290
	Maximum turning length (without chuck)	mm	400
	Standard chuck size	mm	165
CNC System			Fanuc 0i mate - TD/Siemens 828D Basic T
Spindle	Spindle type		Cartridge
	Spindle nose		A2-5
	Spindle bore	mm	47
	Standard bar capacity	mm	25
	Front bearing bore	mm	80
	Std spindle speed	rpm	4000
Power	Spindle motor power Continuous	kw	5.5
	Spindle motor power Intermittent	kw	7.5
	Spindle motor model		Fanuc; beta 6i /Siemens 1 PH7-103
Tooling	Turret		BTP-80
	Number of tools max.		8
	Number of stations		8
	A/f of turret disc	mm	280
	Maximum Boring bar dia.	mm	40
	OD Turning tool size	mm	25 x 25
Axes	Axes motor model		Fanuc; beta 8is / Siemens 1 FK7080
	Type of guide ways		Linear Motion guide ways
	X axis stroke	mm	150
	Z axis stroke	mm	400
	X & Z axis rapid rate	m/min	20
	X & Z ball screw Dia x pitch	mm	32 x 10
Tailstock	Tailstock quill travel	mm	100
	Tailstock base travel	mm	235
Misc.	Tailstock thrust (max)	kgf	300 @12 kg/cm2
	Tailstock quill dia.	mm	80
	Quill taper		MT-4
	Tailstock centre type		Add on
	Coolant tank capacity	litres	110
	System pressure (max)	kg / cm2	30
	Hydraulic pump capacity	litre/min	12
	Power pack tank capacity	litre	45
	Overall machine dimensions	mm	2200 x 1700 x 1775
	Overall machine weight	kg	~ 3800

Fig: 2. CNC Turning Machine

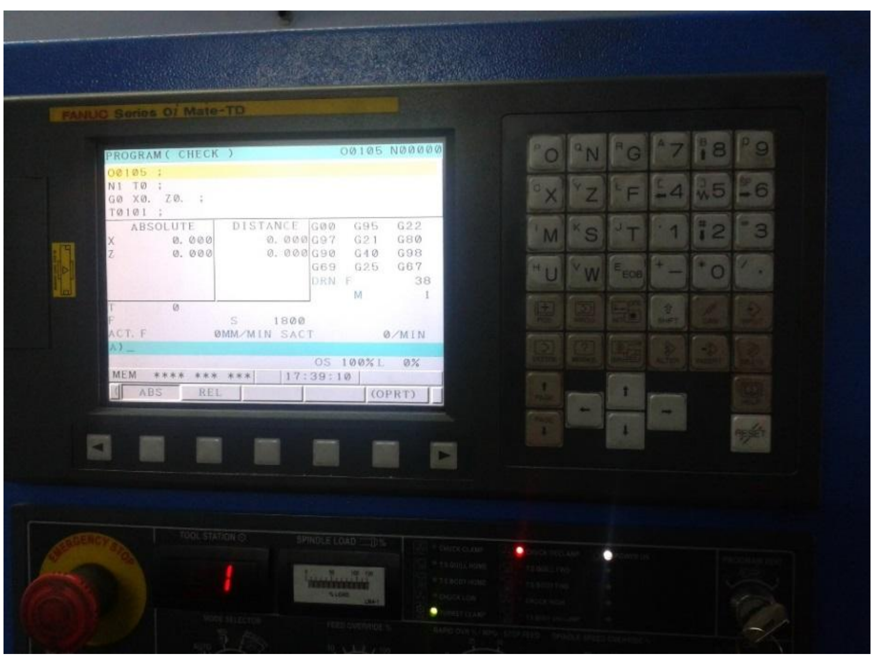

Fig: 3. FANUC Series Oi Mate –TD

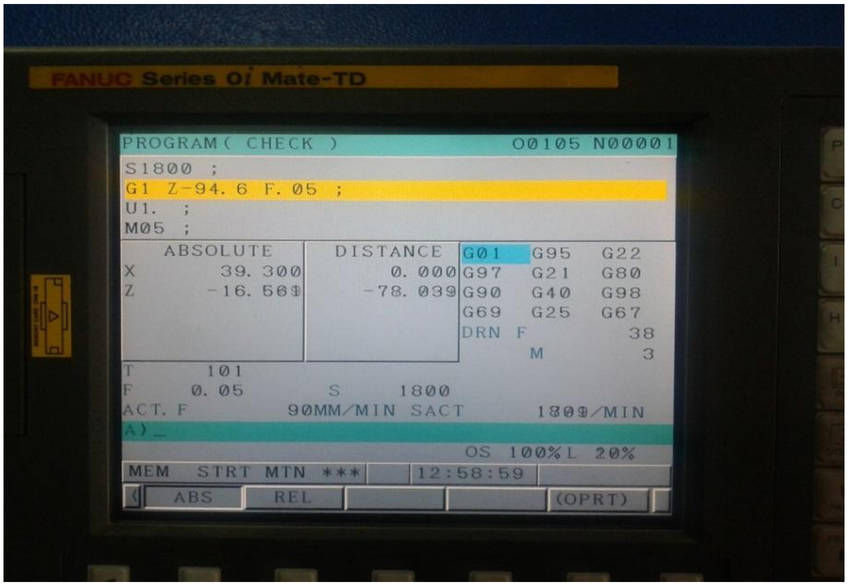

Fig: 4. Program Display Screen

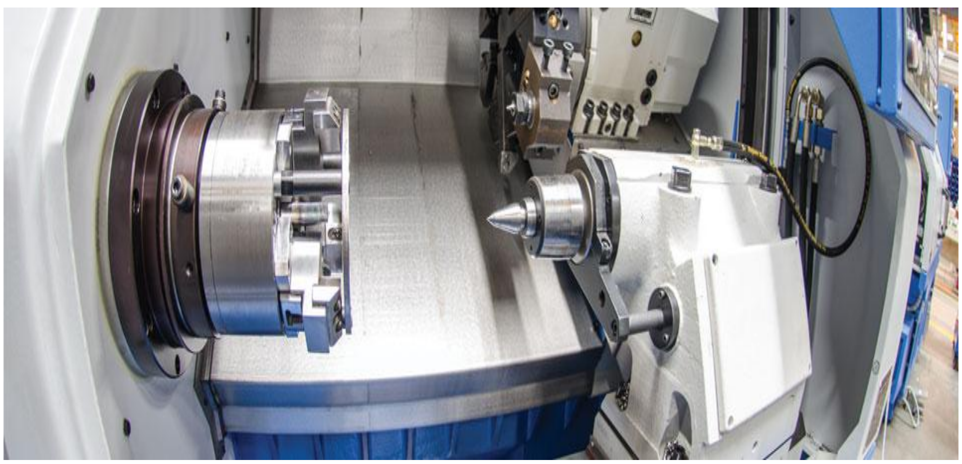

Fig: 5. Spindle View

Fig: 6. Working View and Chips

Fig: 7. Chips Produced While Turning

2.1 Cutting Tool Material

The cutting tool which provided with the CNC turning lathe was a 25 x 25 mm square tool holder with 60 mm length having the positive tool angles.

The tool used was cemented carbide insert type. The geometry of tools selected are with the combinations of three nose radius: 0.4, 0.8, 1.2 and positive Rake angles 16^0, 18^0, 20$^{0.}$ Plate 3.7 shows the inserts and tool holder.

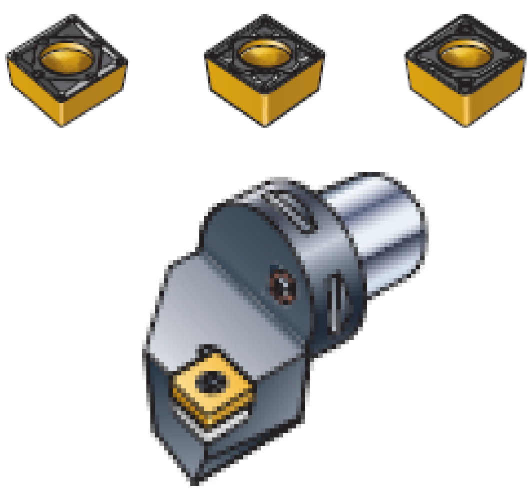

Fig: 8. Inserts and Tool Holder

2.2 Surface Roughness Measuring Instrument

The Surtronic 3+ is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm. The parameters evaluations and other functions of the instrument are microprocessor based. The measurements results are displaced on an LCD screen and can be output to an optional printer or another computer for further results.

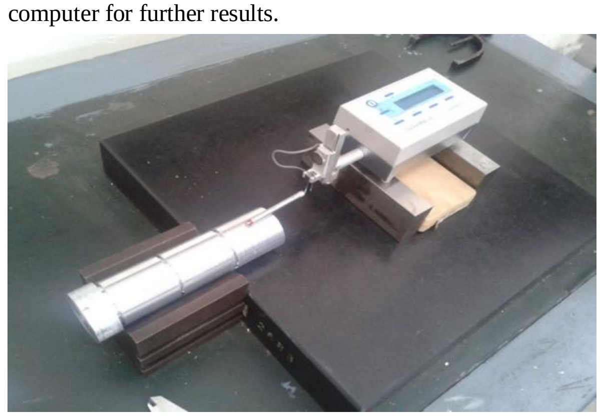

Fig: 9. Roughness Measuring Instrument

Table: 2. Specification of measuring Instrument

Battery:	Alkaline: Minimum 600 Measurements of 4 mm
	Measurements Lengths.
	Ni-Cad: Minimum 200 Measurement of 4 mm Length
	Size: 6 LR 61 (USA / Japan), Fixed Battery
	External Charger (Ni-Cad Only)
	110 /240 V, 50 / 60 Hz
Traverse Unit:	Traverse Speed: 1 mm / Sec
Measurement:	Metric / Inch Preset by DIP-Switch
Cut-off	0.25 mm, 0.8 mm and 2.50 mm

Values:	
Traverse Length:	1, 3, 5, 10, or 25.4 + 0.2 mm At 0.8 mm Cut-off
Display:	LCD-Matrix. 2lines * 16 Characters
Keyboard:	Membrane Switch Panel Tactile
Filters:	Digital Gauss Filters or 2CR Filter (ISO) Selectable By DIP-Switch.
Parameters:	Ra, Rq, Rz (DIN), Ry and Sm
Calculations Time:	Less Than Reversal Time Or 2 Sec Which Ever Is The Longer

Fig: 10. Calibrating view with Measuring Instrument (Surtronic 3+)

2.3 Work Piece Material

Standardized material was selected to ensure consistency of the alloy, which was a common wrought alloy used in industry 6061 Aluminum HINDALCO made in the form of bars with the size of diameter 40 mm 250 mm length so as to fit under the chuck. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. Alloy 6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing. Alloy 6061 is easily welded and joined by various commercial methods. For screw machine applications, alloy 6061 has adequate machinability characteristics in the heat-treated condition.

Table: 3. Chemical Composition of Aluminum Alloy

Element	Weight%
Cu	0.15-0.4
Mg	0.7-1.2
Si	0.4-0.8
Fe	0.7 max
Mn	0.2-0.8
Other	0.4

Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities. Typical properties of aluminium alloy 6061 include:

- Medium to high strength
- Good toughness
- Good surface finish
- Excellent corrosion resistance to atmospheric conditions
- Good corrosion resistance to sea water
- Can be anodized
- Good weldability and brazability
- Good workability
- Widely available

Physical Properties

- Density: 2.7 g/cm^3
- Melting Point: Approx 580°C
- Modulus of Elasticity: 70-80 GPa
- Poissons Ratio: 0.33

Table: 4. Mechanical Properties

Temper	Ultimate Tensile Strength (MPa)	0.2% Proof Stress (MPa)	Brinell Hardness (500kg load, 10mm ball)	Elongation 50mm dia (%)
0	110-152	65-110	30-33	14-16
T1	180	95-96		16
T4	179 min	110 min		
T6	260-310	240-276	95-97	9-13

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Thermal Properties:

Co-Efficient of Thermal Expansion (20-100°C): 23.5x10^{-6} m/m.°C
Thermal Conductivity: 173 W/m.K
Electrical Properties:
Electrical Resistivity: 3.7 – 4.0 x10^{-6} Ω.cm

3. Results and Discussions

The pieces of work material were set so as to conduct turning process three times on a single work piece while calculating the average roughness value, simultaneously by the stylus of the measuring instrument. To more closely replicate typical finish turning processes and to avoid excessive vibrations due to work place dimensional inaccuracies and defects, each work piece was rough-cut just prior to the measured finish cut. Thus simultaneously we could choose the machining zero required for generating cutting profile with reference to our work piece dimensions. The three different values of feed at one depth of cut and at a single speed. Surtronic 3+ instrument available has a pick up with a skid which is used to travel automatically through a drive motor. Thus such travel would at least require a distance of at least 10 mm. Thus we require appropriate surface travel distance on turned aluminum work piece. These dimensions were taken so as to keep travel the stylus on the best surface.

Effect of rake angle

The variation of rake angle with surface roughness for different feed values by keeping nose radius of the tool, cutting speed, and depth of cut as constant have been discussed through graphs.

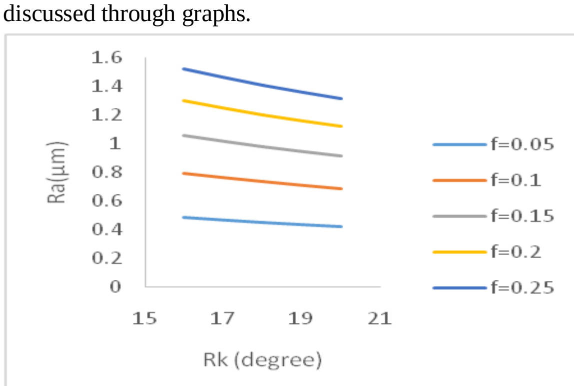

Fig: 11. Graph between Surface Roughness and Rake Angle at Nr 0.4, V 175, d-0.1

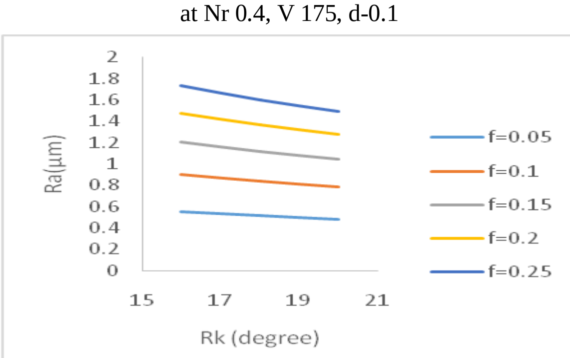

Fig: 12. Graph between Surface Roughness and Rake Angle at Nr 0.4, V 175, d-0.2

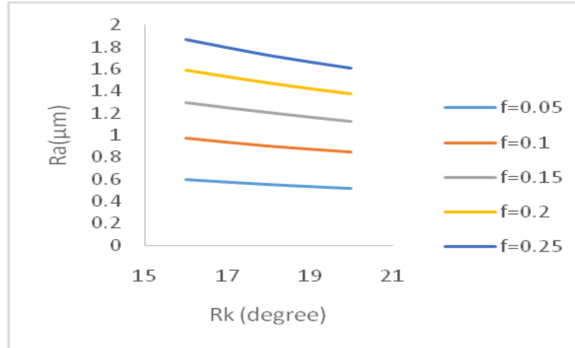

Fig: 13. Graph between Surface Roughness and Rake Angle at Nr 0.4, V 175, d-0

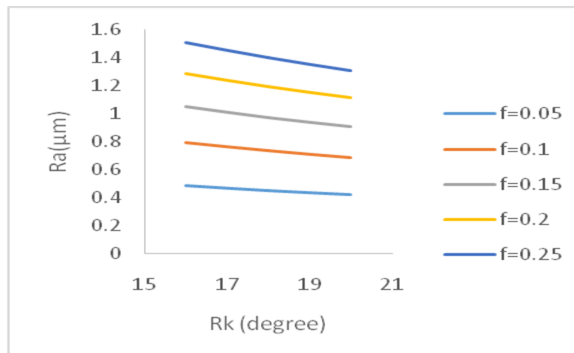

Fig: 14. Graph between Surface Roughness and Rake Angle at Nr 0.4, V 225, d-0.2

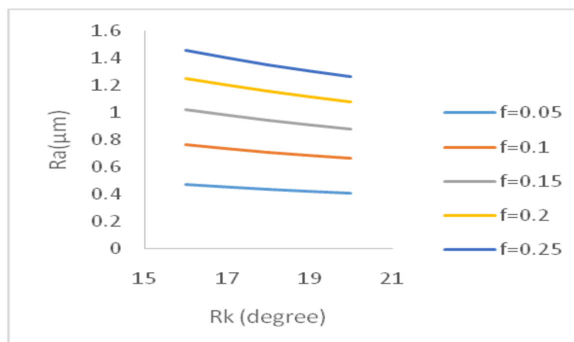

Fig: 15. Graph between Surface Roughness and Rake Angle at Nr 0.4, V 275, d-0.3

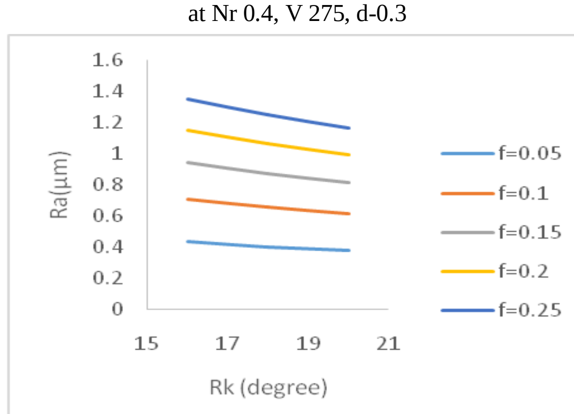

Fig: 16. Graph between Surface Roughness and Rake Angle at Nr 0.8, V 225, d-0.3

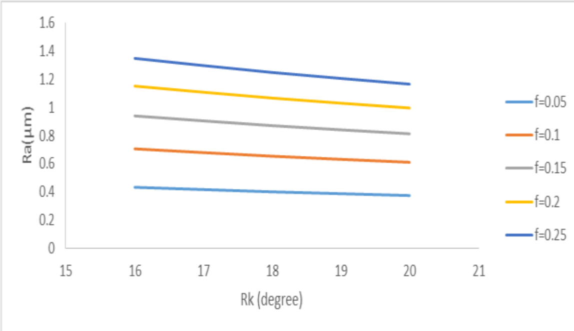

Fig: 17. Graph between surface Roughness and Rake angle at Nr 1.2, V 225, d-0.1

4. Conclusions

This work presented an experimentation approach to study the effect of angle on surface roughness. Strong interactions were observed among the turning parameters. Most significant interactions were found between work materials, feed and cutting speeds. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend.

The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters by varying feed.

Graphs shows the variation of rake angle (deg) with surface roughness (µm) for different feed (mm/rev) values by keeping cutting speed (m/min), depth of cut (mm) and nose radius (mm) as constant.

From the figures 11 to 17 it is also evident that the surface roughness decreases with increase in rake angle.

The minimum and maximum roughness values observed are mentioned below.

The minimum Roughness value 0.263 is at Rk=18, Nr=1.2, d=0.1, V=275 and f=0.05.

The maximum Roughness value 1.865 is at Rk=16, Nr=0.4, d=0.3, V=175 and f=0.25.

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