Effect of Rake Angles on Cutting Forces for A Single Point Cutting Tool

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Abstract – *Metal machining process is one of the prime areas where manufacturing industry thrives. Though the prime parameters that control the quality of the job within the tolerance limit are speed, feed and depth of control, other process parameters also affect the machining. In this paper, effect of rake angle on cutting forces for a single point cutting tool is discussed. During machining, the chip formation depends on the rake angle of the single point cutting tool. Different experiments are carried out to identify the variation in cutting forces with the variation in rake angles. The effect of feed rate on cutting force is also brought under consideration.*

Key Words*: *Rake angle, Single point cutting tool, Cutting force.

1.INTRODUCTION

In metal cutting operation, the position of the cutting tool is important based on which the cutting operation is classified as orthogonal cutting and oblique cutting shown in Figure 1.1 Orthogonal cutting is also known as two dimensional metal cutting in which the cutting edge is normal to the work piece. In turning process the work piece material is rotated and the cutting tool will travel, removes a surface layer (chip) of the work piece material, producing three cutting forces components, i.e. the tangential force (Fy), which acts on the cutting speed direction, the feed force (Fx), which acts on the feed direction and the radial force (Fz), which acts on the direction normal to the cutting speed. In orthogonal cutting no force exists in direction perpendicular to relative motion between tool and work piece. It was observed that the cutting forces are directly depended on the cutting parameters i.e. cutting speed, feed rate, depth of cut, tool material, geometry and work piece material type.

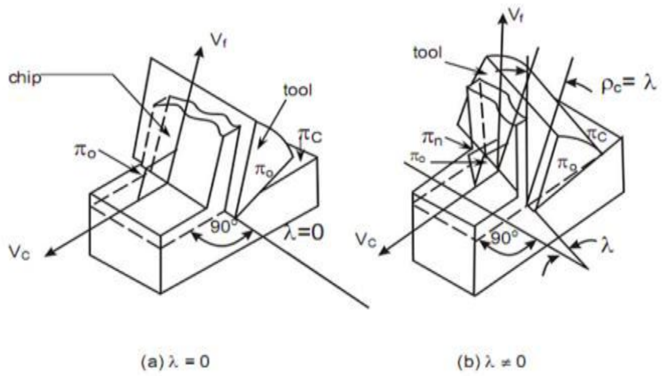

Figure:- 1.1. Turning process (a) Orthogonal turning (b) Oblique turning

1.1 MACHINING PARAMETERS

- Cutting speed: It is defined as the speed at which the cutting edge passes over the material or it is the relative velocity between the cutting tool at the work material
- Feed rate: It is the distance the tool advances into or along the work piece it is the lateral movement of the tool.
- Depth of cut: Is defined as the distance the cutting tool projects below the original surface of the work.
- Tool material
- Tool geometry
- Work piece type and material

1.2 RAKE ANGLE

Rake Angle (α) the angle between the tool face and the plane normal to the surface of the cut and pressing through the tool cutting edge (Edwards, 1993).as shown in figure 1.2 Rake angle is a parameter used in various cutting and machining processes, describing the angle of the cutting face relative to the work. There are two rake angles, namely the back rake angle and side rake angle, both of which help to guide chip flow. There are three types of rake angles: positive, negative, and zero.

Generally positive rake angles:

- Make the tool more sharp and pointed. This reduces the strength of the tool, as the small included angle in the tip may cause it to chip away.
- Reduce cutting forces and power requirements.
- Helps in the formation of continuous chips in ductile materials.
- Can help avoid the formation of a built-up edge.

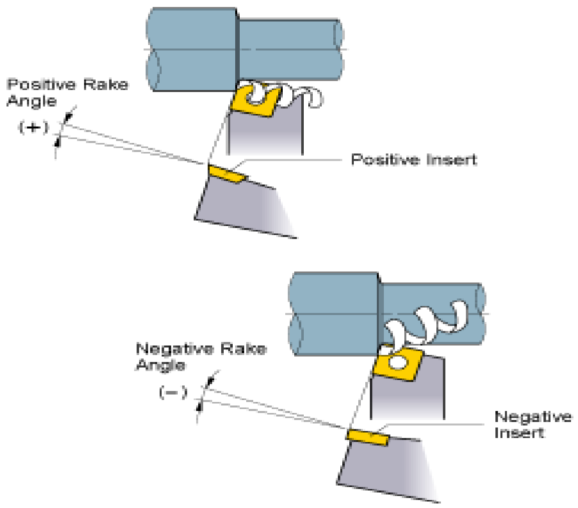

Fig:- 1.2. Chip disposal and rake angle

Negative rake angles, by contrast:

- Make the tool more blunt, increasing the strength of the cutting edge.
- Increase the cutting forces.
- Can increase friction, resulting in higher temperatures.
- Can improve surface finish.

A zero rake angle is the easiest to manufacture, but has a larger crater wear when compared to positive rake angle as the chip slides over the rake face.

Recommended rake angles can vary depending on the material being cut, tool material, depth of cut, cutting speed, machine, and setup. This table summarizes recommended rake angles for single-point turning on a lathe; rake angles for drilling, milling, or sawing are often different.

1.3 CUTTING FORCE COMPONENTS

In orthogonal cutting, the total cutting force F is conveniently resolved into two components in the horizontal and vertical direction, which can be directly measured using a force measuring device called a dynamometer. Also a small radial force will generate in z direction which are shown in Figure 1.3

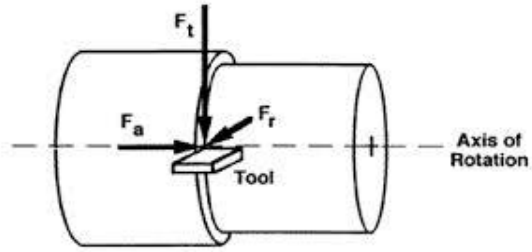

Fig:-1.3. Cutting forces in orthogonal cutting operation

2. LITERATURE SURVEY

In metal removal operations, many researches were carried out in

Bldoukas. [6] :Experimentally investigated the effect of feed rate and tool rake angle by conducting 24 experiments on AISI 1020 steel and found that main cutting force has an increasing tend with the increasing in feed and a decreasing trend as the rake angle increase.

Gunay et al. [7] investigated the effect of rake angle on the main cutting force by conducting experiments on AISI 1040 work piece material. Experimental results were compared with the Empirical results according to Kienzle approach and found that main cutting force has a decreasing trend as the rake angle increased from negative to positive values. The deviation between empirical approach and experiments was in the order of 10–15%.

Saglam, et al.[8]have made a comparison of measured and calculated results of cutting force components and temperature variation generated on the tool tip in turning for different cutting parameters and different tools having various tool geometries while machining AISI 1040 steel hardened at HRc 40. For making a comparison, the main cutting force/tangential force component for different cutting parameters and tool geometries were calculated by Kienzle approach and the temperature values were calculated based on orthogonal cutting mechanism. Finally, the effects of cutting parameters and tool geometry on cutting forces and tool tip temperature were analyzed and found that the average deviation between measured and calculated force results were found as 0.37%. Baldoukas et al.[6] investigated experimentally the influence of cutting depth, tool rake angle and work piece material type on the main cutting force and chip morphology during a turning process. During the experimental procedure they removed chips and were collected and evaluated together with the main. They measured cutting forces, in order to estimate the optimum rake angle for each type material. The experimental results show that the main cutting force has an increasing trend with the increase of the cutting depth.

Lalwani et al.[9]investigated the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel (equivalent to 18Ni(250))maraging steel) using coated ceramic tool. The results show that cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55–93 m/min.

Fang and Jawahir[10] investigated the effects of work piece hardness, cutting edge geometry, feed rate, cutting speed and surface roughness on hardened AISI H13 steel bars with CBN tools. The effects of two-factor interactions of the edge geometry and the work piece hardness, the edge geometry and the feed rate, and the cutting speed and feed rate also appeared to be important. Especially for honed edge geometry and lower work piece surface hardness resulted in better surface roughness.

In this study, the influence of tool rake angles on cutting force was determined during machining of mild steel material AISI 1018 (24mm diameter) , which has well known physical, chemical and machinability properties. During the experimental procedure the forces were measured using a 3-component lathe tool piezoelectric dynamometer.

3.WORK MATERIAL, CUTTING TOOL AND METHOD

AISI 1018 steel has been used as the work piece material to conduct all the experiments. These type of materials are widely used in the industrial applications. For conducting experiments cylindrical bar with diameter of 24 mm were used. Prior to the experiments the specimens were turned with 1 mm cutting depth in order to remove the outer layer, which could appear discontinuous or unexpected hardening distribution due to their extrusion production process. The chemical composition and mechanical properties of the selected work piece material are listed in Table 3.1 and Table 3.2

Table 3.1 Chemical Composition of AISI 1018 Steel

MATERIAL	COMPOSITION
Carbon	0.17%
Silicon	0.27%
Manganese	0.80%
Phosphorus	0.050% max
Sulphur	0.050% max

Table 3.2. Mechanical Properties of AISI 1018 Steel

Finish	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation %	Hardness HB
Bright Drawn	340 - 600	430 - 750	12 min	120 - 220

Single point HSS (High speed steel) cutting tools were used in all the experiments. New tools were used for all experiments to ensure that tool wear is same in all cases. Different rake angles were produced in each tool with the help of a tool cutter and grinder machine and measure the rake angles using profile projector

The various tool rake angles are: 0 º, 8º, 10º, 12º, 14º, 16º, 18º and a constant clearance angle: 10º were used. While turning a ductile material by a sharp tool, the continuous chip would flow over the tool's rake surface and in the direction apparently perpendicular to the principal cutting edge. Practically, the chip may not flow along the orthogonal plane but this assumption is made for an ideal case.

In pure orthogonal cutting, the chip flow along orthogonal plane (Π^o) and principle cutting edge angle (φ=90^0) atypically shown in Fig 3.1 where a pipe like job of uniform thickness is turned (reduced in length) in a center lathe by a turning tool of geometry orthogonal rake (λ=0) and φ=90^0 resulting chip flow along (Π^o) which is also machine longitudinal plane (Πx) in this case.

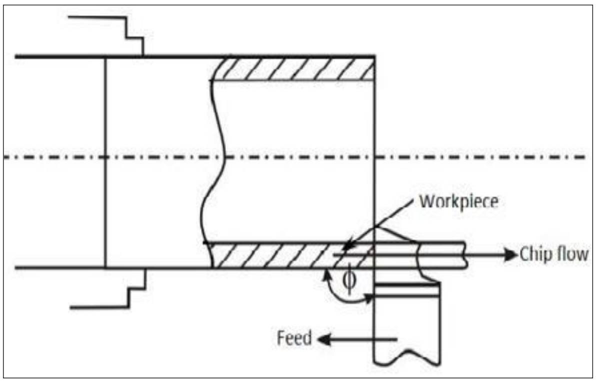

Fig:- 3.1. Pure orthogonal turning (Pipe turning)

4. MACHINE TOOL AND CUTTING CONDITION

Experiments were carried out on a lathe setup as shown in figure 4.1 using High speed steel (HSS) cutting tools for the machining of AISI 1018 cylindrical work piece, which is having diameter 24 mm. A total of 35 experiments were performed with 7 different rake angles 0, 8, 10, 12, 14, 16, 18 at a constant speed of 115 rpm and depth of cut of 1 mm at 5 different feed rates 0.122, 0.143, 0.156, 0.181 and 0.215 as shown in Table 5.1.

Fig:- 4.1. Lathe Setup with 3-Component Dynamometer

5. RESULTS AND DISCUSSION

Turning process has been assumed to be a pure orthogonal process. For such an assumption only 2 components of force must exist in the orthogonal plane.

From the experimental results shown in Table 5.1 and graphs, it is clear that for all cases of rake angle and feed force, the feed force (Fx) > tangential force (Fy) > radial force (F z). It is also clear that the values of F z are very small compare to the other two forces therefore, this force is comparatively small. Hence the experiments carried out can be assumed to be orthogonal turning process.

Table 5.1 Machining Parameters and Experiments Results

Group Number	Rake angle $\gamma 0°$	Expnt Number	Feed (mm/rev)	Fx (N)	Fy (N)	Fz (N)
		1	0.122	294.3	235.44	215.82
		2	0.143	343.35	255.06	235.44
		3	0.156	353.16	274.68	245.25
		4	0.181	392.4	294.3	259.965
1	0°	5	0.215	412.02	313.92	279.585
		1	0.122	225.63	137.34	117.72
		2	0.143	255.06	152.055	127.53
		3	0.156	284.49	166.77	137.34
		4	0.181	294.3	186.39	171.675
2	8°	5	0.215	333.54	196.2	186.39
		1	0.122	168.732	66.708	98.1
		2	0.143	182.466	74.556	108.891
		3	0.156	229.554	80.442	122.625
		4	0.181	241.326	96.138	132.435
3	10°	5	0.215	253.098	116.739	153.036
		1	0.122	171.675	49.05	142.245
		2	0.143	241.326	56.898	146.169
		3	0.156	250.155	66.708	153.036
		4	0.181	264.87	76.518	168.732
4	12°	5	0.215	285.471	81.423	194.238
		1	0.122	414.963	494.424	206.01
		2	0.143	427.716	525.816	223.668
		3	0.156	471.861	547.398	226.611
		4	0.181	513.063	591.543	235.44
5	14°	5	0.215	577.809	645.498	255.06
		1	0.122	158.922	90.252	103.005
		2	0.143	181.485	125.568	117.72
		3	0.156	216.801	133.416	124.587
		4	0.181	229.554	142.245	132.435
6	16°	5	0.215	243.288	158.922	154.998
		1	0.122	86.328	52.974	68.67
		2	0.143	118.701	60.822	79.461
		3	0.156	153.036	70.632	90.252
		4	0.181	155.979	88.29	107.91
7	18°	5	0.215	231.516	100.062	122.625

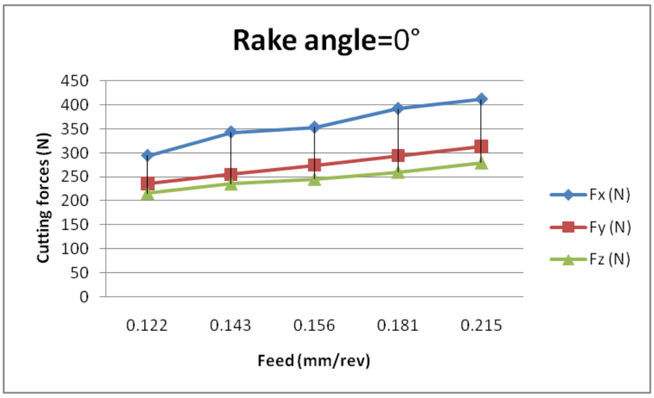

Fig:- 5.1. Variation of cutting forces with feed rate at 0° rake angle.

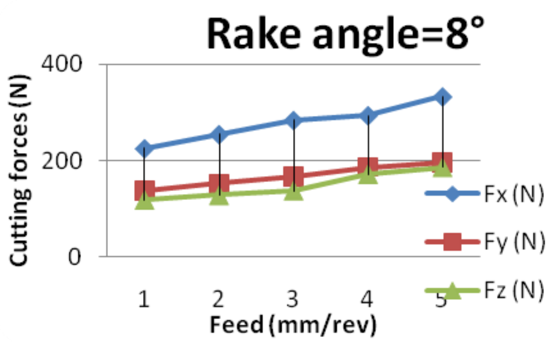

Fig:- 5.2. Variation of cutting forces with feed rate at 8° rake angle

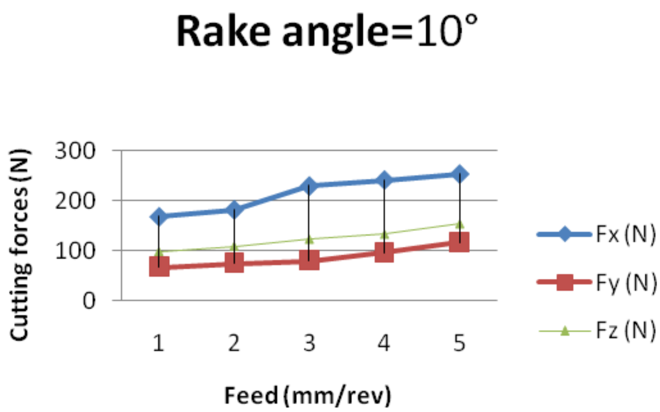

Fig:- 5.3. Variation of cutting forces with feed rate at 10° rake angle

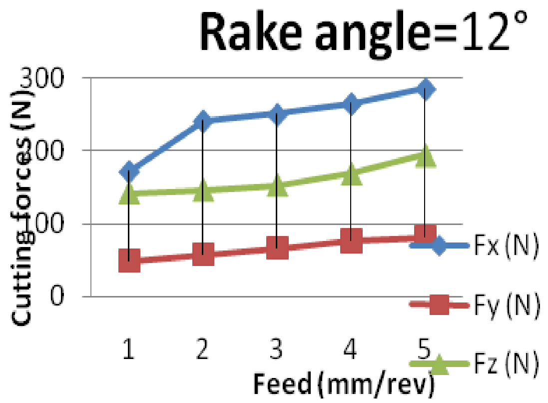

Fig:- 5.4. Variation of cutting forces with feed rate at 12° rake angle

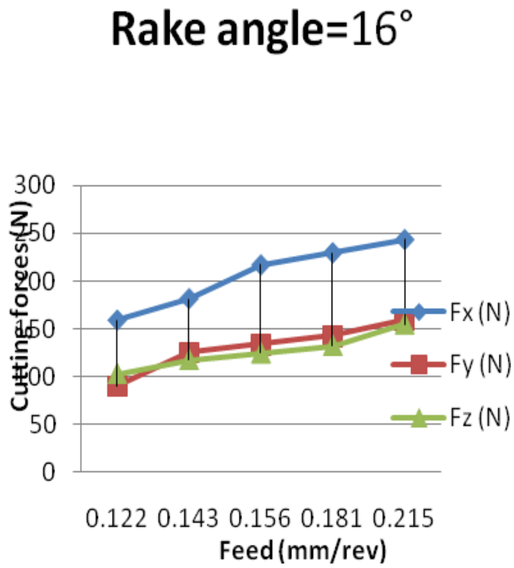

Fig:- 5.6. Variation of cutting forces with feed rate at 16° rake angle

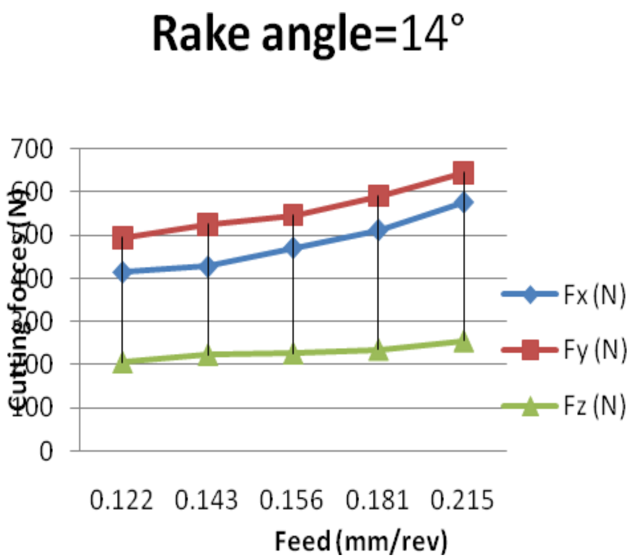

Fig:- 5.5. Variation of cutting forces with feed rate at 14° rake angle

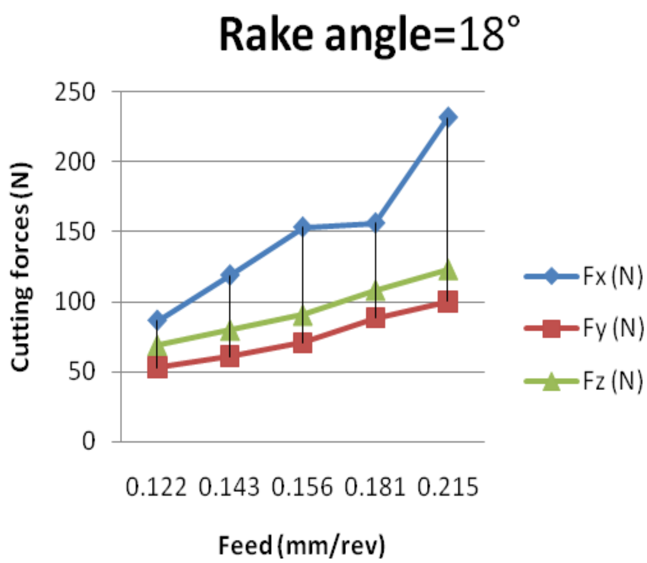

Fig:- 5.7. Variation of cutting forces with feed rate at 18° rake angle

5.2 EFFECT OF FEED RATE AND RAKE ANGLE ON FEED CUTTING FORCE

With increase in feed at higher rake angles, from Table 5.2 and Table 5.3, it is clear that the cutting forces decreases with increase in rake angle and the cutting forces were found to increase continuously with an increase in feed for all rake angles but only a small variation at 14° rake angle. This is due to the fact that the volume of work material coming in contact with the tool or the volume of material being removed also increases with the increase in feed rate. It can also be observed from the Figure. 5.8 and Figure.5.9 that, the cutting forces continuously increase with feed, the increase is more prominent at lower rake angles while less at higher rake angles. This is because the plunging effect of the tool into the work piece material at a greater rake angle overshadows the effect of increase in cutting force

Table. 5.2 Effect of Feed Rate And Rake Angle On Tangential Cutting Force Fx

SL. NO.	EFFECT OF FEED RATE AND RAKE ANGLE ON FEED CUTTING FORCE (Fx)					
	Rake angle	Feed rate(mm/rev)				
		0.122	0.143	0.156	0.181	0.215
1	0°	294.3	343.35	353.16	392.4	412.02
2	8°	225.63	255.06	284.49	294.3	333.54
3	10°	168.73	182.466	229.554	241.326	253.098
4	12°	171.68	241.326	250.155	264.87	285.471
5	14°	414.96	427.716	471.861	513.063	577.809
6	16°	158.92	181.485	216.801	229.554	243.288
7	18°	86.328	118.701	153.036	155.979	231.516

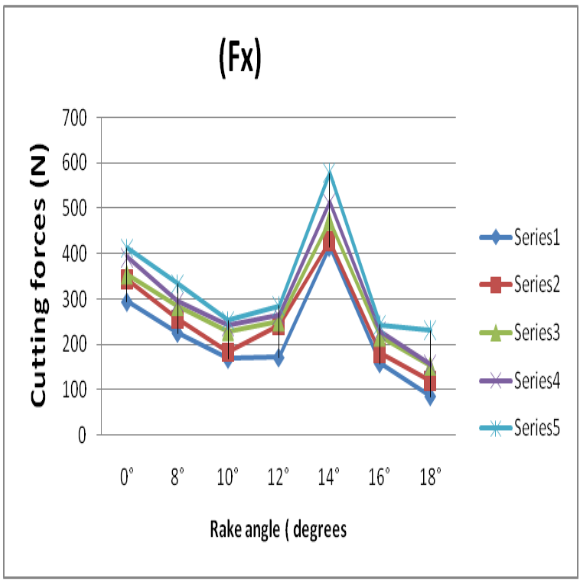

Fig:- 5.8. Change in feed, cutting forces with increase in rake angle for different feeds for Fx

Table. 5.3 Effect Of Feed Rate And Rake Angle On Tangential Cutting Force Fy

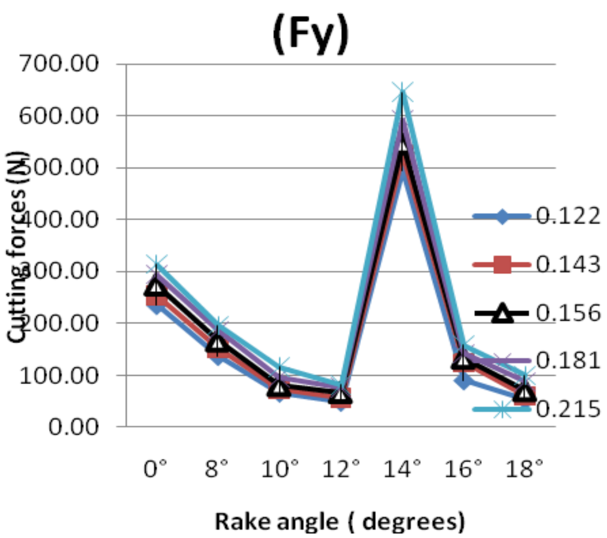

Fig 5.9:- Change in feed, cutting forces with increase in rake angle for various feed for Fy

5.3 VARIATION OF CHIP PATTERN WITH RAKE ANGLES

The chip formation depends on the rake angle directly. As rake angle increases chip formation changes from discontinues continuing chip the following figure 5.10 is the evident to this.

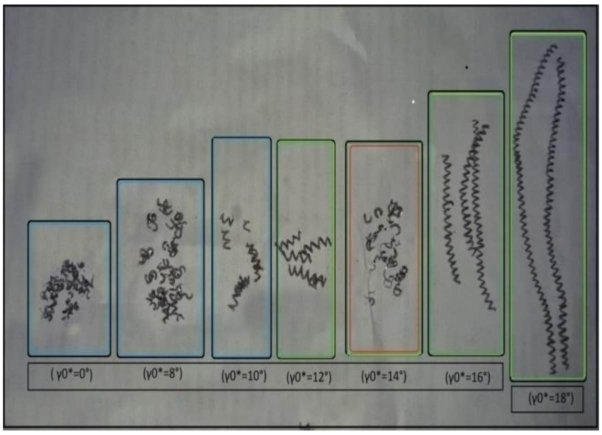

Fig:- 5.10. Variation of chip pattern with rake angle

6. CONCLUSIONS

In this paper a total of 35 experiments were carried out to find the effect of feed rate and rake angles on the cutting forces during orthogonal turning of AISI 1018 steel using HSS cutting tool. From the results of this work the following conclusions can be drawn:

- It was observed that the feed force (Fx) is greater than tangential force (Fy). It is also observed that the radial force (Fz) in the present experimental set-up is very small when compared to the other two force components.
- As the radial force is negligible, the turning of a cylindrical work piece makes it more closure to the orthogonal machining process.
- The cutting forces increase with the increase in feed rate.
- The cutting forces decrease with the increase in rake angle from 00 to 180
- The best rake angles are 120 and 160

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