Effect of rake angles and material properties on chip formation: A Review

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Abstract— This paper presents the review of influences of tool rake angles and material properties on chip formation. Depending on the deformation behavior of the work piece material there are various types of chips. Material properties like ductility and brittleness affect the flow of chip. The rake angle which can give the longest tool life was then selected and observed that rake angle having value of 20° as well as the best surface finish and yielded continuous chips formation. This paper looks at the process of chip formation in metal cutting as being dependent not only on the work piece material but, even on the micro and macro structures of the work piece materials

Index Terms— Rake angle, Surface finish, Type of chips, Work piece material.

I. INTRODUCTION

The problem of chip formation generally is a very important one to the manufacturers. This is not unconnected with the problem associated with the classification of chips and most importantly, the theory behind the chip formation. This paper is looking into the formation of segmented (which we shall be referring to as continuous with built up edge) chips during turning of titanium, stainless steel and mild steel and its alloys in a semi-finished cutting process. The classification of chips is generally into three groups: discontinuous chips; continuous chips and chips with built-up edges. The type of chip that forms depends on many factors, of both tool and material. Rake angles are ground or formed on the top of face of the tool. The quest for profit maximization in manufacturing process makes it necessary for engineers and scientist to explore the optimum processes which requires less time and minimum energy for maximum output. Depending on the deformation behavior of the work piece material, there are different mechanisms of chip formation with either continuous or discontinuous. The analyses provide information on the mechanisms of chip formation, the plastic deformations in the chip formation zone and the position of the shear plane. The process for continuous chip formation can be described using a model of five deformation zones. The main part of the plastic deformation takes place in the primary shear zone in the form of shear deformation. In the secondary shear zones in front of the rake face and the flank face, the work piece material is additionally deformed under the influence of high friction forces. A stagnant zone (zone with high pressure from all sides) develops in front of the cutting edge. The actual separation of work piece material also takes place in this zone.
II. AIMS AND OBJECTIVES OF WORK

Rake angle is a parameter used in various cutting and machining processes. Realistically, the rake angle is not an independent variable in the process of tool geometry selection because the effect of the rake angle on chip formation. The aims and objectives of the present study are as follows:

1. To study the influence of rake angle on metal turning process.
2. To study the effect of material selection.
3. To study the effect of chips on tool life.
4. To study the chip control method.

III. DEFINITION OF TERMS

Rake Angle (α): This is the angle between the tool face and the plane normal to the surface of the cut and pressing through the tool cutting edge. Generally three types of rake angle considered, i.e. positive rake angles, negative rake angles & zero rake angles.

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.

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.

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.

Clearance angle (β): This is also known as relief angle, it is the angle between the tool face adjacent to the surface of the cut. This angle helps to eliminate rubbing between the tool and the surface being cut and hence reduces friction to the barest minimum. According to Charles’ (1971) a clearance angle of 60 to 80 is large enough to prevent excessive rubbing of the tool on the work.

Chips: The cutting tool while machining on the work piece removes an amount of material that is called an chip. As the tool advances into the work piece, the metal in front of the tool compressed and when the compression limit of the metal has been exceeded, it is separated from the work piece and flows plastically in the form of chips.

The chip produced, whatever the cutting conditions are, may belong to one of the following three types:

- Continuous chip.
- Discontinuous chip.
- Built-up edge.

Continuous Chip: These chips are produced while machining more ductile materials. This type of chip is more desirable, about 95% of the power expended for metal removal is used in the deformation taking place in shear zone, and remaining power about 5% is expended in stored elastic energy in the work piece and friction. Some ideal conditions that promote continuous chips in metal cutting are:-
- Small chip thickness(fine feed);
- Small cutting edge;
- Large rake angle;
- High cutting speed;
- Ductile work material.

Discontinuous chip: These chips are usually produced while cutting more brittle materials like gray cast iron, bronze and hard brass. In this type, the chip produced is in the form of discontinuous segments. These types of chips are easier from view point of chip disposal; however the cutting force becomes unstable with the variation.
coinciding with the fracturing cycle. They also provide better surface finish. However, in case of ductile materials they cause poor surface finish and low tool life. Discontinuous chips are likely to be produced under the following condition:

- Low cutting speeds;
- Small rake angles;
- Higher depth of cut.

**Built-up Chip**: When machining ductile materials, condition of high local temperature and extreme pressure in the cutting zone and also high friction in the tool-chip interface may cause the work material to adhere or weld to the cutting edge of the tool forming the built-up edge (BUE).

- This causes the finished surface to be rough.
- In general low cutting speed, high feed and small rake angles are conducive to BUE formation.
- Presence of BUE increases power consumption.

**Tool Life**: This is the period of cutting with the tool measured between regrinding. It is simply the time between regrinding or re-sharpening of tools. It refers to the continuous cutting period, regrinding is not generally delayed until the tool has broken down completely, the tool might have to be ground for example, because the quality of the surface finish is deteriorating or there is tendency of the tool not to maintain dimensional accuracy and so on.

**CHIP CONTROL**:

- The control of chips in high speed production turning, is important to protect both the operator and the tool. The long continuous chip that curls round the cutting tool has sharp edges and can inflict deep, painful and dangerous cuts. It should never be handled with bare hands.
- The usual procedure to avoid the formation of continuous chips to break the chip intermittently with a chip breaker, which clamped on the rake face of the cutting tool.
- The Chip breaker decreases the radius of curvature of the chip.
- A wide variety of cutting tools and inserts with chip breaker features are available. However with soft work piece materials, such as mild steel, aluminum chip breaker generally not as effective.
- With proper lubrication the flow of chips can be control and also better tool life can be given.

**IV. LITERATURE VIEW**

Many surveys have been done considering different rake angles. Researchers have long investigated its effect on cutting forces, temperature and tool life etc. The works of various authors from various fields have been referred from 2000 onwards. In this paper, previous research and important findings in the orthogonal machining process is critically reviewed.

Peng Lo 2000[1] worked on the elastic plastic finite element method so as to investigate the effect of tool rake angle on the chip formed and the machined work piece in precision cutting process. The results indicates that with increase in rake angle cutting force, maximum equivalent strain on the section decreases and top of the chip contour become smoother.

Fang and Jawahir 2002 [3] predicted three important machining parameters, i.e. the cutting force ratio, chip thickness, and chip back-flow angle, on the basis of: the universal slip-line mode.

Again Fang 2002 [4] discussed and analyzed the forces, chip thickness, and natural tool–chip contact length in machining with a double-rake-angled tool and demonstrated that double-rake-angled tool increases the thrust forces in comparison with single rake angled tool. It is found that tool–chip friction on the tool secondary rake face plays an important role in machining than the tool–chip friction on the tool primary rake face.

Tool chip length is one of the important parameter in orthogonal cutting. Toropov and Lim Ko 2003[5] they proposed a new formula for tool chip contact length as a result there is same correspondence between theoretical and experimental results. This research could also be helpful for the analysis of, temperature phenomena, tool strength and wear problems.

Fang 2002 [6] proposed a slip-line model in favor of the tool–chip contact on the tool secondary rake face. Chip curl in machining was also taken in to account.

Huang and Liang 2003 [7] focused on the finish turning in which the applied feed rate and depth of cut are usually very small. They initially predicted the chip formation forces by transforming the 3-D cutting geometry into an equivalent 2-D cutting geometry.

Sutter 2005 [8] in orthogonal turning process at very high speeds investigated the chip geometries formed during cutting by the help of high speed numerical camera with a very short time aperture.

Son et al. 2006 [9] showed that because of large rake angle there is unstable cutting process without continuous chip. In this investigation, they applied vibration cutting method for the possibility to reduce the minimum cutting thickness by changing the friction coefficient between tool and work piece. The vibration cutting method is applied to increase the friction coefficient. On the basis of theoretical investigation and experimental verification results show that the cutting technology is efficient by decreasing the minimum cutting thickness and increasing the friction coefficient. Depending upon materials and vibration conditions the minimum cutting thickness was considerably reduced by 0.02–0.04 mm.

Fang and Fang 2007 [10] worked on the theoretical and experimental results in finish machining with a rounded edge tool. The analytical results concludes that with increase in cutting speed and feed rate the tool-chip friction along tool rake face and the round tool edge decreases on the other hand the FE (Finite Element) shows that near the round tool edge high temperature exists there.

Yanda et al. 2010 [11] focused on the effectiveness of rake angle. They found that cutting force decreases by increasing rake angle in positive side whereas cutting force increases by increasing rake angle in negative side.

Totis and Sortino 2011 [12] worked on the measurement of cutting forces in turning by specifically designed an innovative dynamometer for tri axial cutting on modern CNC lathes. The measured cutting forces were finally compared with theoretical values obtained from mathematical modeling.

Kosaraju et al. 2011[13] presented the effects of rake angle and feed rate on cutting forces in orthogonal metal cutting process. On the basis of results they found that with increase in feed rate and rake angle cutting force increases and decreases respectively.

V. DISCUSSION

From the literature review it has been found that the cutting parameters (rake angle, depth of cut, material property and cutting speed) have considerable effects on the tool life. With the increased in positive rake angle, the cutting forces are decreased which means that less force/power is required. The results also suggest that the rake angles and the material property influence the flow of chip. Because chip flow is directed by the rake angles, hence by the optimum designs of rake angles and selecting better material the flow of chips can be controlled and tool life also be increased.
VI. CONCLUSION

In this study, with the help of effective rake angles, while machining (Turning) mild steel with HSS turning tools, the results of this review suggests that rake angle of 20 gave the longest tool life, yielded continuous chips formation and produced the best surface finish. The results obtained from the literature survey it is found that:

- The cutting force decreases as the tool rake angle increases.
- With increase in feed rate, this tends increase in cutting force.
- The increase in absolute value of negative tool rake angle and cutting speed these results in the decrement of tool chip friction.
- The tool tip temperature increases with an increase in cutting speed.
- Ductile material gives continuous chip and longer tool life, while brittle material gives discontinuous chip and shorter tool life.
- Hence ductile material gives better result than brittle material.

REFERENCES


