MEASUREMENT AND A NEW EMPIRICAL FORMULA OF THE CHIP FLOW ANGLE IN TURNING

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Abstract: The reliability of machining operations is an essential requirement of modern automatic manufacturing system. In the machining operations, in which unbroken chips are the major obstacles for automation, reliability implies chip control as a major aspect. To improve chip control is necessity for automated machining. In turning operation chip control is difficult especially for mild steel because chips are continuous. Chip control is closely related to the chip flow and it plays also a predominant role in the effective control of chip formation and chip breaking for the easy and safe disposal of chips, as well as for protecting the surface-integrity of the workpiece. Although the chip flow direction plays an important role in the chip control and a way to calculate the chip flow angle in a wide range of cutting conditions has been subjected in some papers by several researchers, it has not been established satisfactorily yet. Obviously, to predict the chip flow direction is becoming an important subject for the development of suitable chip breakers and the automation of turning operations. In this study, using different indexable inserts and cutting conditions for turning of mild steel, the chip flow directions were measured and a new empirical formula for prediction of the chip flow direction in term of the tool cutting edge geometry and cutting conditions was obtained by using of mathematical statistics.
Keywords: Measurement, Turning, Chip Flow, Chip Control

1   INTRODUCTION

In metal cutting with automated machining, very reliable machining processes are required. Chip control, a very complex problem, affects the reliability and efficiency greatly. It depends on all parameters and conditions of cutting processes and closely related to the chip flow. The nature of chip flow and its direction affect the chip curling and breaking processes. Chip flow direction may change the motion of the chip and the effective groove width of the chip breaker therefore the chip flow direction plays an important role in the chip control.

The chip flow direction is one of the important factors affecting the effective rake angle of the tool which in turn has influences on the cutting forces and the tool life. Therefore the role of the chip flow direction is subjected to be studied in the metal cutting theory. Because of the chip flow angle is defined by chip flow direction, is affected a lot of factors, difficult to analyse them theoretically. The chip flow angle, as a dependent variable in cutting process, should be considered as random variables. It means that their values are distributed randomly under the same cutting conditions.

Even though some formulas on it have been obtained, its practical applications are greatly limited due to the simplifications. Under the light of these facts, in this paper, the role of chip flow angle was studied experimentally and by use of mathematical statistics a regression equation to calculate the chip flow angle including three important factories was established directly from the experimental data covering a wider range of cutting conditions.

The analysis of prediction precision of the regression equation is also carried out. It is shown by experiments that this formula can be applied to predict and control the chip flow dependably and conveniently in a wider range of cutting conditions.

Nomenclature; v: Cutting speed (m/min), a: Depth of cut (mm), f: Feedrate (mm/rev),
r: Tool nose radius (mm), υ: Chip side flow angle (°), γ : Rake angle (°), λ: Inclination angle (°),
ε_r: Plan angle of the tool (°), x: Principle cutting edge angle (°), K: Constant

2   CHIP FLOW

During machining, the chip leaves in a direction from the chip formation zone. In machining by using a flat-faced tool, the chip flow may have one of the three possible basic forms, as shown Figure 1: A straight line, at an angle (chip flow direction) with the cutting direction (A), a circular form on the rake face (B) and a circular form perpendicular to the rake face (C) on the rake face. Two basic angle are so important for chip flow, which one of these is chip side flow angle and the another is chip back flow angle. The chip side flow angle is defined as the angle between a plane perpendicular to the direction of feeding for a single-point cutting tool, and a plane through the path of the chip intersecting the reference plane in line parallel to the cutting direction (Colweell, 1954).
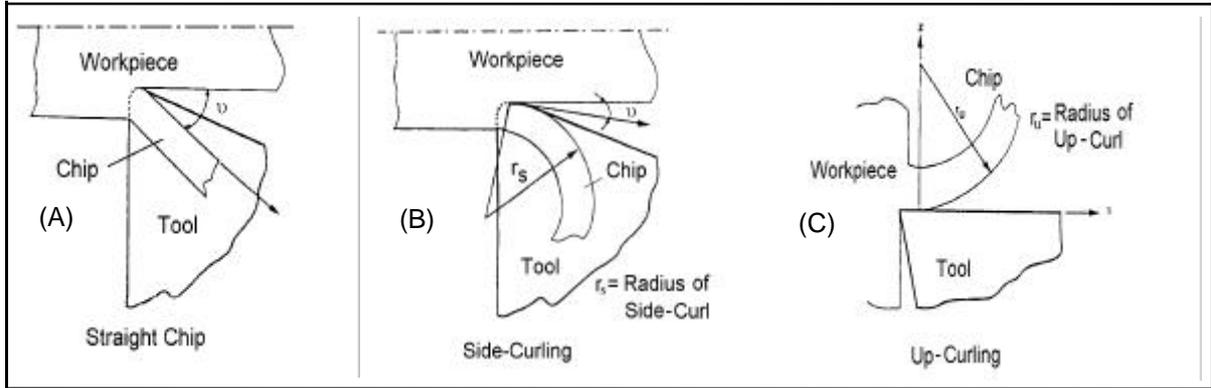

Figure 1. Three Basic Chip Flow Forms (Jewahir,1993)

2.1   Chip Side Flow

Many researchers worked on the chip flow angle. Some of them chose single cutting edge orthogonal machining, because of its simple geometric feature, or oblique cutting. They assumed that the cutting edge is perfectly sharp and that the metal cutting operation can be likened to a simple cutting process with a wedge-shaped tool having an inclined cutting edge. The various models for estimating chip side flow angle in turning have been achieved by using a plane-faced tools.

During the last five decades, significant findings on it have been reported and several researchers purposed different mathematical models for chip flow angle and verified them experimentally.

Stabler (1951) purposed the well known rule of the chip flow angle in oblique cutting as fallows;

$$\upsilon = \lambda \tag{1}$$

In his latter work (Stabler 1964), he also suggested that the resultant chip flow direction could be found by vectorially adding the velocities at the two cutting edges.

Colwell (1954) showed that the chip flows approximately perpendicular to the cutting edge chord representing the major axis of the cut. According to Colwell equations, which are given below, the chip side flow angle (υ) can be determined by depth of cut (a), feed rate (f), nose radius (r) and side cutting edge angle (x).

$$\upsilon = \tan^{-1}\left(\frac{\sqrt{2r.a - a^2 + f/2}}{a}\right) \qquad \frac{a}{r} < (1 - \cos(x)) \tag{2}$$

$$\upsilon = \tan^{-1}\left(\frac{a/\tan(x) + r.\tan(x/2) + f/2}{a}\right) \qquad \frac{a}{r} \geq (1 - \cos(x)) \tag{3}$$

Okushima and Minato (1959) suggested that the chip side flow is the vectorial sum of elemental flow angles over the entire length of the edge that cuts. Another researcher Zorev(1966) derived an equation for the chip flow angle which consider the magnitudes of the forces acting on the side and end cutting edges. Armarego (1971) established an equation for chip flow for general oblique machining. His work analyses the basic methodologies adopted by the previous researches.

Spaan (1971) reviewed and compared all models for chip flow angle, and derived an empirical equation to predict the chip flow angle.

$$\upsilon = 33,3\left(\frac{r}{a}\right) + 3,3 + K.\lambda \tag{4}$$

This equation was modified to include the effect of feed at UMIST in 1990.

Jiang (1984) established a regression equation, as follow, to calculate the chip flow angle from the experimental data.

$$\upsilon = 0,208.\,a^{(-0,744)}.\,f^{(0,424)}.\left(r+0,45\right)^{(0,682)}.\left(x-16\right)^{(1,28)}.0,988^{(\gamma)} + 0,62.\lambda \tag{5}$$

This equation includes six important factors of cutting conditions.

Young at.al. (1987) derived an equation for predicting the chip flow from the estimated direction of the resultant friction force on the tool rake face. A recent work at the University of Kentucky, Ghosh and Jawahir (1993) developed a new method for chip flow angle in oblique machining.

Although many researchers worked on the chip flow angle in orthogonal machining up to now, the most of the models and equations to predict the chip flow angle are complex and not supply a good approximation to the practice.

In this study, using different indexable inserts and cutting conditions for turning of mild steel, it was aimed to derive an equation, including three important factors, feed rate, dept of cut, and tool nose radius, that is more practical for use and gives a good approximation with the experimental data.

3 EXPERIMENTAL STUDIES

Basing on the researchers before, to find out the relation between chip side flow angle (υ) and the three factors, depth of cut, feed rate and nose radius, and obtain an equation for chip flow angle, a series of orthogonal tests have been arranged. In order to get enough data for obtaining an equation experimental points have been chosen suitably so that more information can be obtained from less experiments. Therefore, experimental variables have been taken as:

depth of cut (a): 0.25 mm, 0.50 mm, 0.75 mm, 1.00 mm, 1.25 mm,

feed rate (f): 0.101 mm/rev, 0.204 mm/rev, 0.409 mm/rev, 0.818 mm/rev,

tool nose radius (r): 0.4 mm, 0.8 mm, 1.2 mm.

Totally sixty tests carried out by using different cutting conditions in each times.

Orthogonal tests as external turning processes have been realised on Stankoimport 1A616 model universal lathe. Indexable inserts were TPUN 160304-P40, TPUN 160308-P40, TPUN 160312-P40, (ISO). CTGPR2525 (ISO) tool holder was used. The principle cutting angles of tools were x=90°, λ= 0°, γ=+5° , ε_r=60°. In Figure 2 indexable inserts and tool holder are shown. Cutting speed were taken 105 m/min. in the all experiments. In every experimental, turning was carried out without coolant and using sharp indexable insert. A cylindrical workpiece (ϕ 70 mm) made of St37 was firstly machined so as to be have some steps as shown Figure 3 and then used it for experiments.
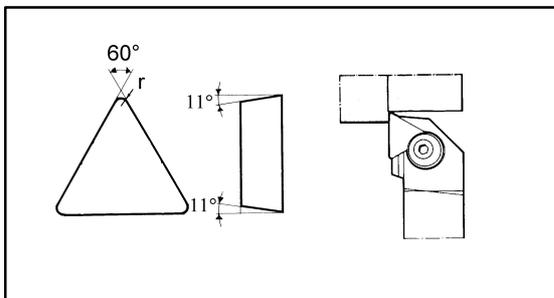

Figure 2. Schematic drawing of the indexable insert and the tool holder
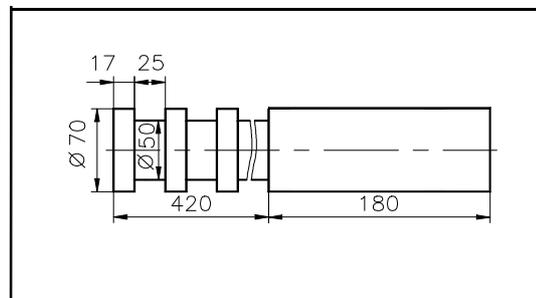

Figure 3. The workpiece used in turning

During turning, at the end of the each step, machining was stopped and in order to obtain chip side flow angle, tool rake face was observed by using microscope. Painting and photographic method were used to measure chip side flow angle. According to this method, before machining, tool

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rake face of cutting tool is painted with a paint that resists high temperatures and creates strongly adhesive layer with substrate. After machining of workpiece, using a camera setting on a microscope, the trace that takes from with abrasive effect of chip flowing on the rake face of cutting tool and defines chip side flow is observed and taken a photograph. Using mentioned method, and Olympus Vuace model microscope, for each test a photograph was taken and then chip side flow angle was measured by using a protractor. A sample of chip trace on the tool rake face is shown in Figure 4.
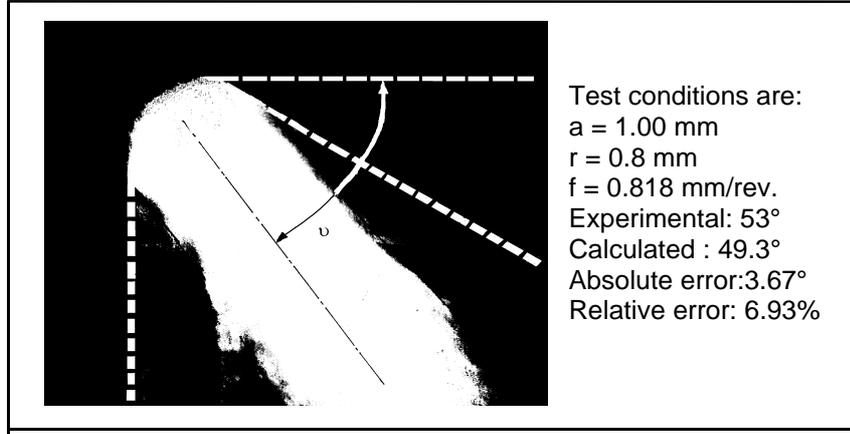

Test conditions are:
a = 1.00 mm
r = 0.8 mm
f = 0.818 mm/rev.
Experimental: 53°
Calculated : 49.3°
Absolute error:3.67°
Relative error: 6.93%

Figure 4. A photograph of the trace on the rake face of the tool that shows chip side flow direction.

The chip side flow angles that was obtained from tests versus depth of cut and feed rate are given Figure 5 for different tool noses in a three dimension graphics.
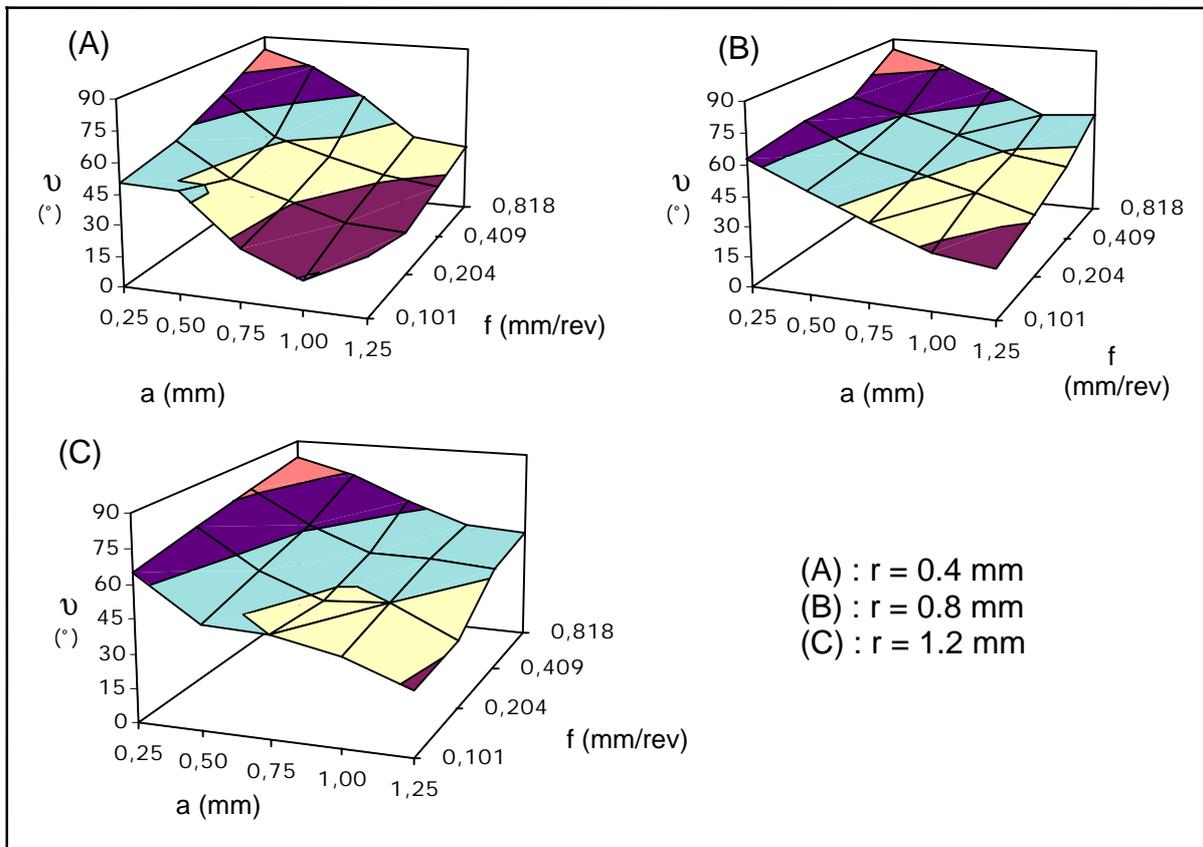

(A) : r = 0.4 mm
(B) : r = 0.8 mm
(C) : r = 1.2 mm

Figure 5. Chip side flow that measured from tests versus depth of cut and feedrate for different tool noses.

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4 THE REGRESSION EQUATION AND VARIANCE ANALYSES

It may be assumed that the chip flow angle is a random variable. Feed rate, depth of cut and tool nose radius are independent variables that can be known exactly. Regression function that describes the correlation between the chip flow angle and three independent variables (feed rate, depth of cut and tool nose radius) has been found out as fallow:

$$\upsilon = 54{,}8276 . \left(\frac{f^{(0.2247)} . r^{(0.2715)}}{a^{(0.4488)}} \right) \tag{6}$$

Variance analyses was carried out. It is seem that the regression equation is highly significant and the influences of three independent variables are very important. Absolute and relative errors were also obtained. For sixty experiments, average absolute error was 4,6° and average relative error was 10,46%. All analyses were shown that this equation is reliable and applicable.

5 RESULTS AND CONCLUSSION

In this study, the effect of feed rate, depth of cut and tool nose radius on the chip flow angle have been researched by experimental orthogonal cutting tests and based on the experimental data the new empirical formula of the chip flow angle including three important factors has been obtained by use of statistical method.

As shown Figure 6, the chip flow angle decreases with the increasing of depth of cut and the decreasing of feed rate. Tool nose radius affects the chip flow angle. When the nose radius of tool is increased, the chip flow angle shows an increase.

If we modified Collweel's (2-3), Spaan's and Jiang's (4,5) equations so that they can give the results for cutting and tool parameters that are taken in this work and compare each of them with the others, in the range of cutting conditions, the best results, approximating experimental findings, that are found out from the equations of chip flow angle belong to our equation (6). Figure 6 shows some points that has been taken from experiments and calculated from the equations (2-3-4-5) and (6) for comparing them.

In this situation, it can be stated that the equation (6) obtained by using multiply regression is more suitable for predicting of the chip side flow angle during turning under the orthogonal cutting conditions of mild steel by using standard tool holder and indexable inserts.
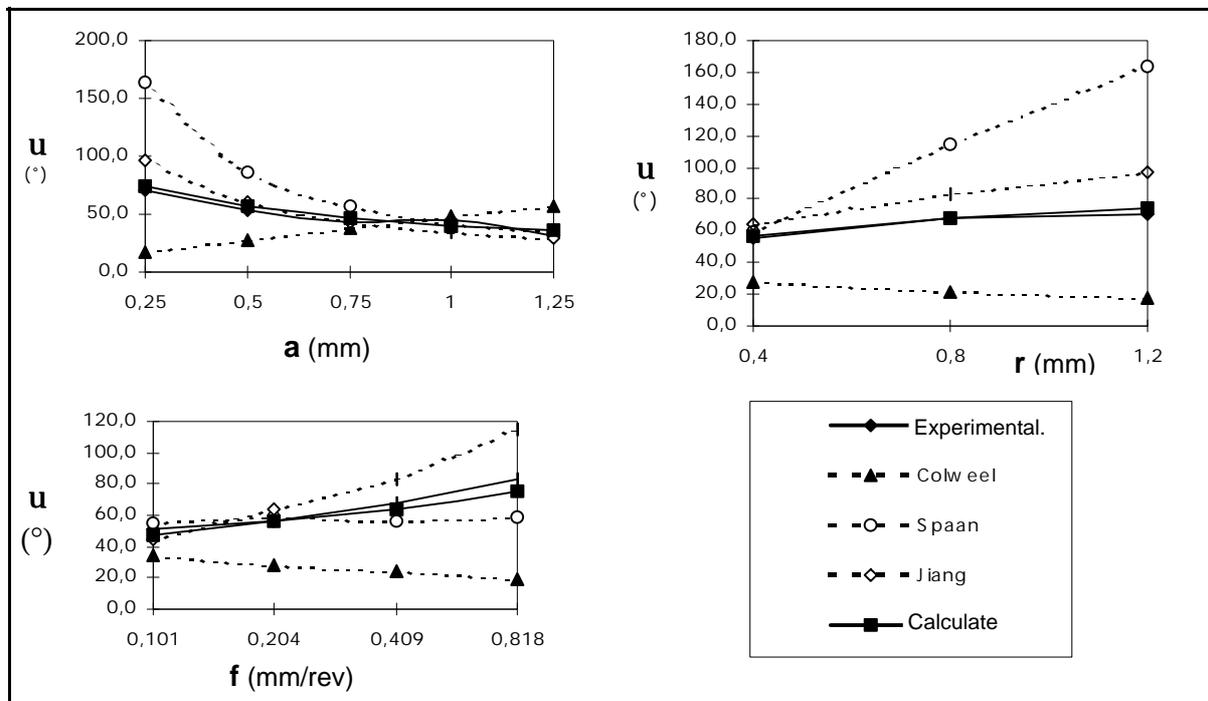

Figure 6. The effects of the depth of cut, feed rate and nose radius on chip side flow angle and comparison of the relations with experimental data.

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