

THE CHIP-TOOL CONTACT LENGTH IN ORTHOGONAL METAL CUTTING

VALERY MARINOV

Department of Mechanical Engineering, Eastern Mediterranean University
Gazimagusa, TRNC (via Mersin 10), Turkey
tel. ++90 392 854-3108; fax ++90 392 365-1217; e-mail: vmarinov@menet.me.emu.edu.tr

ABSTRACT

The chip-tool contact length plays an important role in metal cutting theory as it defines together with the shear angle, tool orthogonal rake and undeformed chip thickness the geometry of the chip formation zone and therefore the entire process of metal cutting. A lot of theoretical and experimental studies deal with the problem of shear angle prediction, but amazingly not to much attention is paid to the chip-tool contact length. The present research work was carried out as an attempt to fill this gap. Since most predictive models of metal cutting are considered in 2-D formulation with typical work material mild carbon steel, the present work was limited to these conditions. The experiments were carried out as series of tests in order to map the relationship between the chip-tool contact length and cutting velocity, undeformed chip thickness, and cutting tool orthogonal rake when turning 0.2 % carbon steel using P25 carbide cutting tools with two rake angles. The chip-tool contact length was measured from the traces on the tool rake. Experimental results were compared with results from other authors.

KEYWORDS: chip-tool contact length, orthogonal metal cutting

1. INTRODUCTION

Dimensional Analysis

In an attempt to determine the nature of the relationship that is to be expected for the chip-tool contact length l_c , a dimensional analysis was performed. For a given combination of tool and work materials, in addition to l_c three more quantities are necessary to define completely the geometry of the chip formation zone: the tool orthogonal rake γ_0 , the undeformed chip thickness a , and the chip thickness a_1 (or shear angle ϕ^\dagger). In case of two-dimensional orthogonal cutting, the width of cut does not affect the geometry of the chip formation. Cutting velocity V is known to change the chip-tool contact length and the shear angle but indirectly, through the influence on the cutting temperature and hence the work material properties.

It would then appear that the several quantities that might figure in a determination of l_c are

[†] Only if a simple single shear plane cutting model is considered. Otherwise, the geometry of the process will be more complex and more quantities have to be added.

those listed in Table 1.

Table 1. Dimensional analysis for chip-tool contact length

Quantity	Symbol	Dimensions
Chip-tool contact length	l_c	Length
Tool orthogonal rake	γ_o	...
Undeformed chip thickness	a	Length
Chip thickness	a_1	Length

When a dimensional analysis is performed in the usual manner we obtain

$$\frac{l_c}{a} = f\left(\frac{a_1}{a}\right) \quad (1)$$

which states that the chip-tool contact length is a function of a_1 and a only.

Previous results

In their machining theory, Oxley and co-workers [1] assumed retarded flow at the chip-tool interface with frictional conditions defined by so-called angle of friction λ . The normal stress distribution on the rake face is assumed uniform and the vector of the resultant cutting force intercept the tool rake face at distance $\frac{1}{2}l_c$. Under this assumption, l_c is calculated from the equation

$$l_c = \frac{a \sin \theta}{\cos \lambda \sin \phi} \left\{ 1 + \frac{Cn}{3[1 + 2(\frac{1}{4}\pi - \phi) - Cn]} \right\} \quad (2)$$

where θ is the angle made by resultant cutting force with the shear plane, n and C are constants. In order this equation to be directly implemented, angles that define the geometry of cutting must be known in advanced. Equation (2) can be rearranged in such a way so that l_c to be expressed as a function only of ϕ and material properties.

Similar equation was suggested by Tay and co-workers [2] given by

$$\frac{l_c}{a} = \frac{\sin \theta}{\cos \lambda \sin \phi} \quad (3)$$

Vinogradov [3] proposed l_c to be calculated as

$$\frac{l_c}{a} = \frac{\sin \frac{\pi}{4}}{\sin \phi \sin \left[\frac{\pi}{4} + \phi - \gamma_o \right]} \quad (4)$$

The equation reasoned by Abuladze [4] is given by

$$\frac{l_c}{a} = \left(\frac{a_1}{a}\right)^{0.1} \left[\frac{a_1}{a} (1 - \tan \gamma_o) + \frac{1}{\cos \gamma_o} \right] \quad (5)$$

The experimental results of Poletika [5] showed that the undeformed chip thickness has the major effect on the contact length. The equation proposed by Poletika is given by

$$\frac{l_c}{a} = 2.05 \frac{a_1}{a} - 0.55 \quad (6)$$

It is obvious, that this equation coincides with the proposed model in equation (1).

For work material (0.42...0.48) %C carbon steel and tool material similar to P10 ISO grade, Zhang, Liu and Hu [6] reported the following empirical equation for l_c :

$$l_c = 8.677 \cdot 10^{-5} a^{0.515} V^{-0.065} (90^\circ - \gamma_o)^{0.733} \quad (7)$$

The equation has been derived for a range of cutting conditions cutting velocity $V = 30 \dots 130$ m/min, undeformed chip thickness $a = 0.15 \dots 0.39$ mm, tool orthogonal rake $\gamma_o = 0^\circ, 14^\circ, \text{ and } 30^\circ$. The cutting tool had a 0.2-mm negative primary land at -6° and -30° , which caused a "dead metal zone" to appear and to change the cutting mechanism. Under these circumstances, equation (3) cannot be applied to the case of sharp cutting edge but is useful for some comparisons in trends over the range of cutting conditions used.

Sadik and Lindström [7], Barrow and co-workers [8], and other researchers also reported similar results.

2. EXPERIMENTAL RESULTS

In order to provide data to derive equation (1), a large number of turning tests on work material 0.18 %C steel were made at the Eastern Mediterranean University. All tests were performed using tools with brazed carbide inserts of P25. After brazing, tools were carefully ground on a tool grinder with tool orthogonal clearance $\alpha_o = 6^\circ$, tool cutting edge angle $\kappa_r = 90^\circ$, tool cutting edge inclination $\lambda_s = 0^\circ$, and tool orthogonal rake $\gamma_o = 0^\circ$ and 10° . In order to reduce the variation of cutting speed across the cutting edge, large workpieces of approximately 230-mm diameter were used. The workpieces were first bored to produce tubes of 1-mm wall thickness. The experimental set-up is shown in Fig.1. The experimental results of Young *et al.* [9] showed that the tube diameter does not significantly change the nature of cutting conditions, therefore, they can be to a great extent considered orthogonal. Experiments were carried out over a range of cutting conditions as follows:

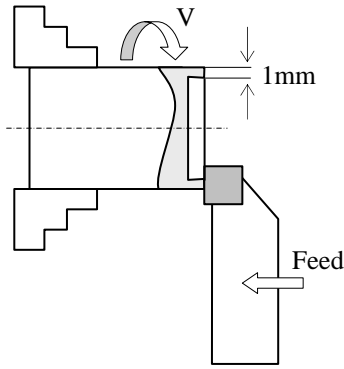


Fig.1. Experimental set-up

$V = 91 \dots 291$ m/min, $a = 0.1 \dots 0.35$ mm, $b = 1$ mm, no cutting fluids. The total contact length was obtained measuring chip traces on the rake face by an instrumental measuring loupe. The tool rake face was carefully polished and cleaned before each test. Each test was performed on a new section of the cutting edge to eliminate wear effects. Averaged values for l_c are shown plotted against a in Fig.2 for two rake angles over the range of cutting velocities. To obtain equation (1), the same experimental results are plotted in Fig.3 in a dimensionless form l_c/a vs. a_1/a . The experimental results are well correlated with a coefficient of determination 0.9228, and give a good fit with a relation of the form

$$\frac{l_c}{a} = 1.61 \frac{a_1}{a} - 0.28 \quad (8)$$

For this equation residual mean square was 0.01179.

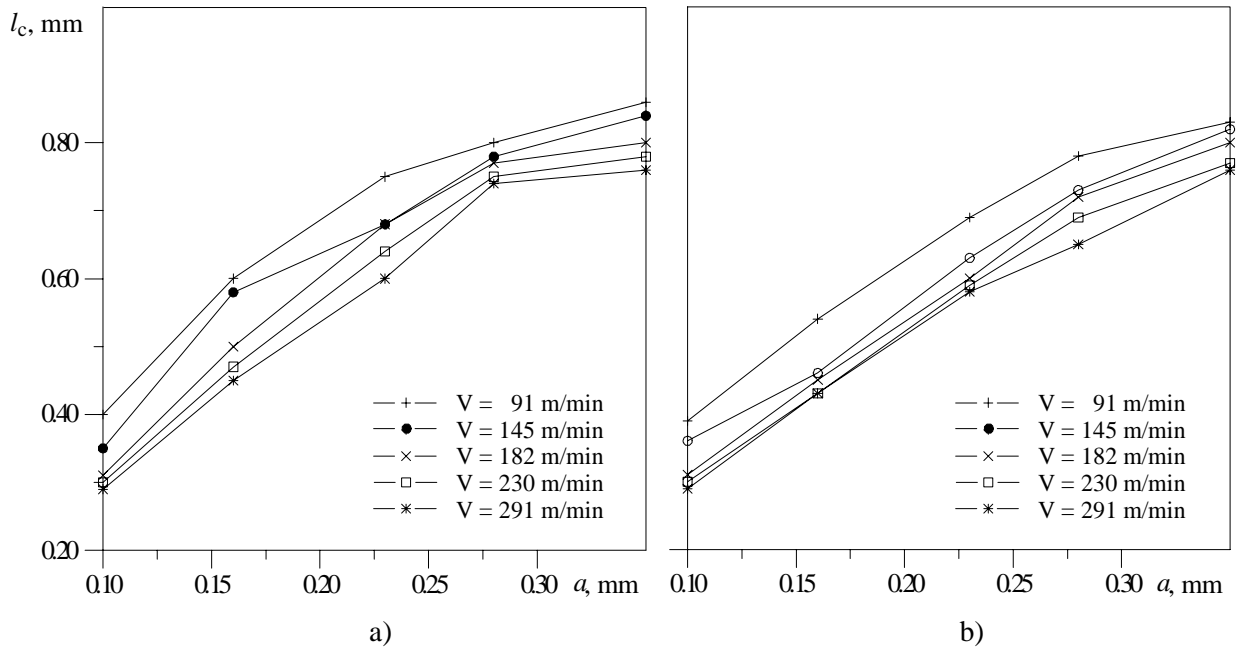


Fig.2. The effect of undeformed chip thickness on chip-tool contact length for five cutting speeds

a) $\gamma_o = 0^\circ$, b) $\gamma_o = 10^\circ$

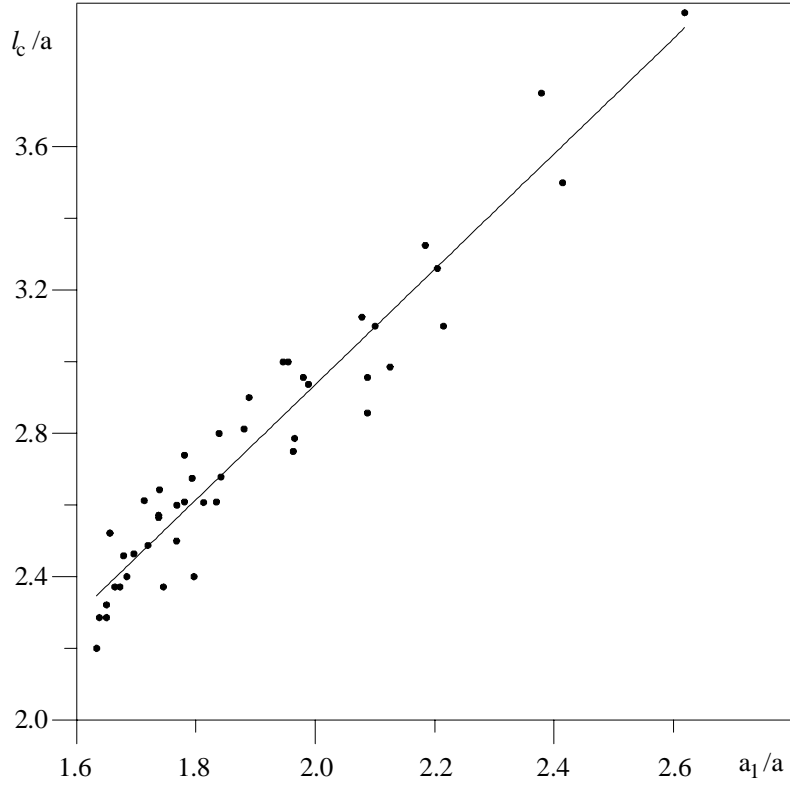


Fig.3. Experimental results for the chip-tool contact length: solid line represents equation (8).

Equation (8) cannot be considered as a fully predictive since it will require experimental data for a_1 or ϕ in advance. Additional analysis of the experimental data was performed in order to map the relationship between the chip-tool contact length and cutting velocity, undeformed chip thickness, and cutting tool orthogonal rake. The analysis yielded a polynomial equation given by

$$l_c = (0.08 - 1.10^{-3}V + 4.813a + 1.204 \cdot 10^{-6}V^2 + 1.10^{-3}Va - 6.771a^2) \left(\frac{90 - \gamma_0}{90} \right)^{0.7} \quad (9)$$

which gives l_c in *mm* for V in *m/min*, a in *mm* and γ_0 in *deg*.

3. DISCUSSION

From Fig. 2 it follows that chip-tool contact length depends mainly on undeformed chip thickness. This conclusion well supported by some other results as mentioned before is not a surprise as from geometry of cutting it is obvious that l_c must include $a \cos \gamma_0$ and therefore any increase of a will lead directly to an increase of l_c . But this dependence is not as linear as suggested by Sadik and Lindström [7]. Increasing a inevitably increases the shear angle ϕ and consequently the chip thickness a_1 thus making the influence of a on l_c non-linear as it is evident in Fig.2. Interestingly, such non-linear dependence between a and l_c could be seen in results presented by Sadik and Lindström as well. In the plot showing the effect of cutting speed and feed on the contact length this non-linearity is

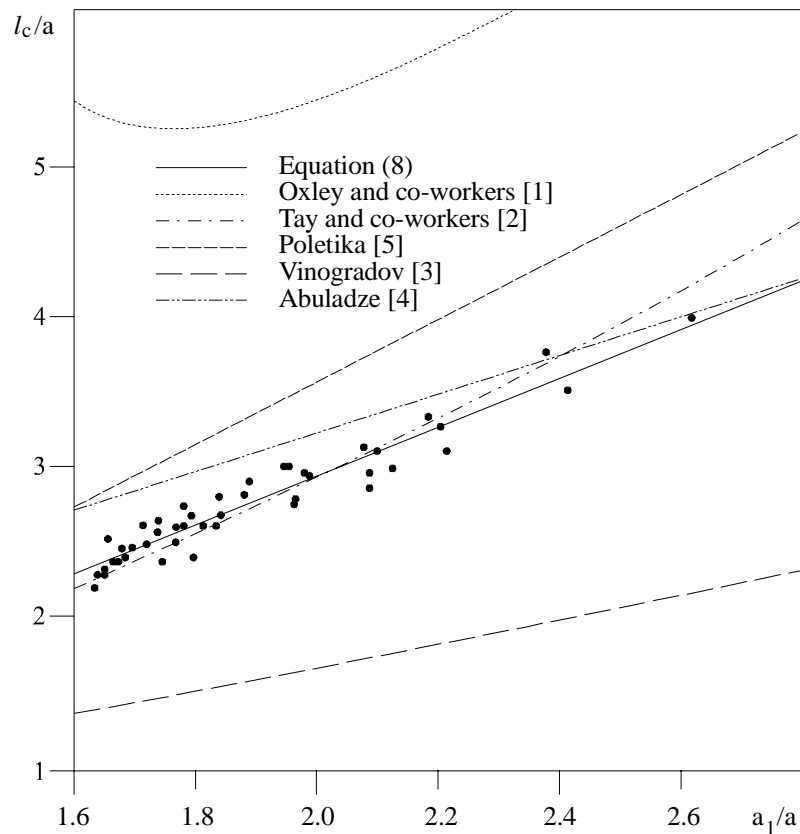


Fig.4. Comparison between the experimental results (symbols) and different equations for the chip-tool contact length. Work material 0.18 %C steel, $\gamma_o = 0^\circ$, for models proposed by Oxley *et al.* and Tay *et al.* $C = 5.9$ and $n = 0.2$.

obvious over the entire speed range. Nevertheless, authors concluded that the relation between l_c and feed is linear. The present experimental results and those reported by Poletika [5] suggest such linearity but between the dimensionless parameters l_c/a and a_1/a as it is evident in equation (8) and Fig. 3.

It is worth to compare equation (8) with results from other authors. Results of the comparison are plotted in Fig. 4 together with the experimental data from Fig.3. All models except for the model proposed by Oxley and co-workers are linear or approximately linear over the range of cutting conditions considered. Most models, especially the model proposed by Tay and co-workers agree well with the experimental results. Both models proposed by Oxley and co-workers and Tay and co-workers require additional data about work material properties (n) and process constants (C) which were taken constant for the purposes of the present comparison. In the predictive models, these factors vary with ϕ , which would result in different plots in Fig. 4. The equation (6) proposed by Poletika yields higher values for l_c in comparison with equation (8) but it should be pointed out that Poletika derived equation (6) for a very wide range of cutting conditions and variety of ferrous and non-ferrous work materials. For the work material and the range of cutting conditions concerned in the present paper, equation (8) correlates well with experimental results presented by Poletika.

The influence of V and γ_o is not so obvious as this of a and has to be explained through their

influence on the shear angle ϕ and hence the chip thickness a_f . Chip-tool contact length decreases with V and γ_o , which was also observed in other experiments, *viz.*, Sadik and Lindström [7], Barrow and co-workers [8].

4. CONCLUSIONS

The dimensional analysis showed that l_c is a function of a_f and a only. The dimensionless equation derived exhibits a linear dependence between l_c/a and a_f/a over the range of cutting conditions assumed. A polynomial equation was obtained to map the relation between l_c and V , a , and γ_o . From all process parameters, the undeformed chip thickness has a major effect on l_c . Chip-tool contact length decreases with V and γ_o and their influence has to be explained through their influence on the shear angle ϕ and hence the chip thickness a_f .

REFERENCES

- /1/ Oxley P. L. B., 1989, *The Mechanics of Machining*, Ellis Horwood, Chichester.
- /2/ Tay A. O., Stevenson M. G., de Vahl G. and Oxley P. L. B., 1976, A numerical method for calculating temperature distributions in machining from force and shear angle measurement, *International Journal of Machine Tool Design and Research*, vol. 16, 335-349.
- /3/ Vinogradov A. A., 1985, *Physical Foundations of the Process of Drilling Difficult-to-Cut Materials Using Carbide Drills*, Naukova Dumka, Kiev. (in Russian)
- /4/ In: Loladze T. N., 1982, *Strength and Wear Resistance of Cutting Tools*, Mashinostroenie, Moscow. (in Russian)
- /5/ Poletika M. F., 1965, Contact phenomena in metal cutting, *Proceedings of the Tomsk Polytechnics*, p. 133. (in Russian)
- /6/ Zhang H. T., Liu P. D. and Hu R. S., 1991, A three-zone model and solution of shear angle in orthogonal machining, *Wear*, vol. 143, 29-43.
- /7/ Sadik M. I. and Lindström B., 1993, The role of tool-chip contact length in metal cutting, *Journal of Materials Processing Technology*, vol. 37, 613-627.
- /8/ Barrow G., Graham W., Kurimoto T. and Leong Y. F., 1982, Determination of rake face stress distribution in orthogonal machining, *International Journal of Machine Tool Design and Research*, vol. 22, 75-85.
- /9/ Young H. T., Mathew P. and Oxley P. L. B., 1987, Allowing for nose radius effects in predicting the chip flow direction and cutting forces in bar turning, *Proceedings of the Institution of Mechanical Engineers, Part C*, vol. 201 (C3), 213-226.