CONTACT ON TOOL FLANK FACE IN MACHINING

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Abstract

It is probable and has being observed that during machining there is contact between the machined surface and tool flank face due to spring back of the material passing the cutting edge. This recovery suggests that a minimum depth of cut is expected. The contact length and the minimum depth of cut is estimated in this work using theoretical relationship and experimental measurements from residual cutting forces (ploughing forces). These forces are obtained measuring the cutting forces for different feed rates and than extrapolating back to zero feed rate. The theoretical calculation of the contact using the equation derived for the static situation does not give consistent results, both for the length of the contact and the stress involved in the process. However there is some experimental evidences that indicates the proportion of the contact, which could be due to elastic recovery of the material.

Keywords: Machining, Mechanical Contact, Tribology

1.INTRODUCTION

The majority of work in metal cutting admits contact between the workpiece and the tool flank face only if there is flank wear and the tool is not sharp. The focus of attention is the region of contact on the rake face. Therefore in a turning operation with a single point tool three forces are considered: the cutting force in the direction of cutting speed; feed force in the direction of feed and thrust force in the direction perpendicular to the feed. These forces are a consequence of the force necessary to shear the material on the primary shear plane to form the chip and the new machined surface and the force necessary to overcome the resistance to chip movement on the rake face of the tool, the secondary shear zone. The contact on the flank face is not taken into account concerning the distribution of force.

Considering that the material machined is not a perfect plastic material, there could be some elastic deformation involved in the process. In fact the temperature achieved by the cutting zone and the high strain rate can affect the behaviour of the material during cutting. Because the strain rates during machining are so high, and there are no means to test a material under such conditions, the fundamental behaviour of the material is unknown. However for most ductile materials some elastic deformation during cut could be considered. Thus this elastic behaviour of the material suggests a contact of the machined surface with the tool flank face. It means that the tool needs to penetrate a specific depth into the material before starting to cut it. In other words, there is a minimum depth of cut that will depend on many factors, but mainly on the properties of the material. For values less than this minimum the material will not be cut, just be deformed.

Some authors named the forces due to the contact between workpiece surface and tool flank face residual cutting forces or ploughing force, Albrecht (1960), and believe that they are independent of feed rate. Therefore considering that there is no BUE the residual forces can be calculated by means of extrapolation of a curve of cutting forces back to zero feed rate. This is done assuming that the residual forces, and so the contact length on the flank face, will not change with feed. Thus the forces during cutting are composed of the force necessary to shear the material and form chip and new surface on the shear zone, the force to overcome friction (and shear the chip) on the rake face and the residual forces on the flank face.

When there is a BUE, depending on its size and shape the situation can change. The BUE formed avoids contact with the flank face, but there is still elastic recovery after the material passes the BUE. However if extrapolation of the forces as above is used to calculate the residual cutting forces, the results will be misleading, because the conditions in the cutting zone will change with the feed rate when a BUE is present.

2.CONTACT LENGTH ON THE FLANK FACE

The usual representation of orthogonal cutting considers that the machined surface is being formed exactly at the cutting edge and will not have contact with the tool flank face. It is reasonable to consider chip formation by shearing action along a plane inclined with the direction of cut.

In the orthogonal cutting when the tool touches the workpiece, before it starts to cut some elastic deformation takes place. As the tool advances towards the workpiece the elastic limit of the material is reached and it starts to flow plastically. At this point there is no plastic deformation of the material but elastic deflection and no cutting. Eventually point is reached where the plastic deformation above the cutting edge compels the material to shear along the primary shear plane, and starts the chip formation. This contact with the tool rake face has a great effect on machining and the secondary shear zone. Figure 1 illustrates these situations.

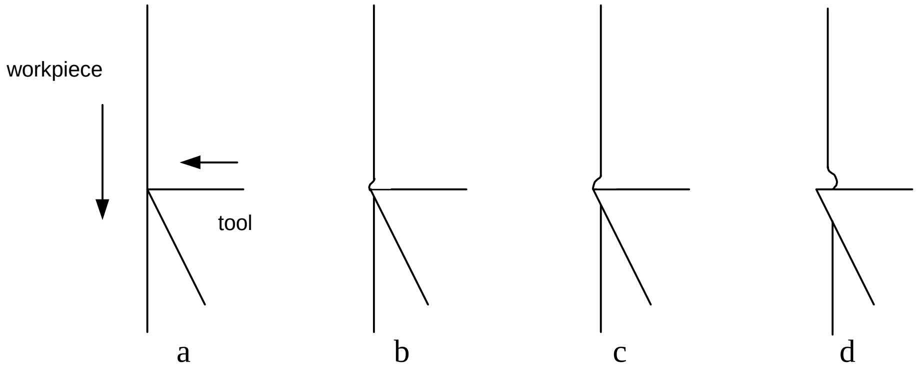

Figure 1. Initiation of cut: a-tool touches the workpiece; b-elastic deformation; c-plastic deformation; d-about to start to cut.

After the cut has started the situation can change and either there is no more contact on the flank face or the contact can continue independent of what happens above the cutting edge. Wallbank (1978) found evidence of this contact below the cutting edge when cutting different materials, suggesting that the contact can still exist during the cut.

Considering a tool with a rounded cutting edge instead of sharp wedge, when it touches the workpiece, and before it starts to cut, the movement is similar to the ploughing action of a hard particle sliding against a rigid plastic body. In this case the ridge of deformed material is pushed along ahead of the slider, no material is removed from the surface, instead the material flows beneath the particle. Three modes of sliding can be distinguished: cutting, wedge formation, and ploughing. The attack angle (inclination of the rake face) of the slider (particle in abrasion) and the conditions of the interface determine the transition between them. In experiments using a single particle as abrasive, the inclination of the cutting face determines whether material is removed or not, Sedricks et al. (1963).

When the sliding action results in removal of material the attack angle is the angle between the rake face and the direction of cutting speed. However, considering a rounded cutting edge at the moment when the tool touches the surface of the workpiece (without cutting) this angle is zero. As the tool penetrates into the surface this angle varies from zero to the attack angle of the tool. Therefore if the tool edge geometry is a cylinder then the depth of penetration will control the attack angle. Consequently the mode of sliding will depend on the penetration.

Figure 2 illustrates the effect of the attack angle or depth of penetration in the sliding mode for three materials. A sphere sliding against a plane surface. The interfacial shear strength, f, is the ratio between the shear stress at the interface (tangential force necessary to continue the movement) and the shear yield stress of the material of the plane surface.

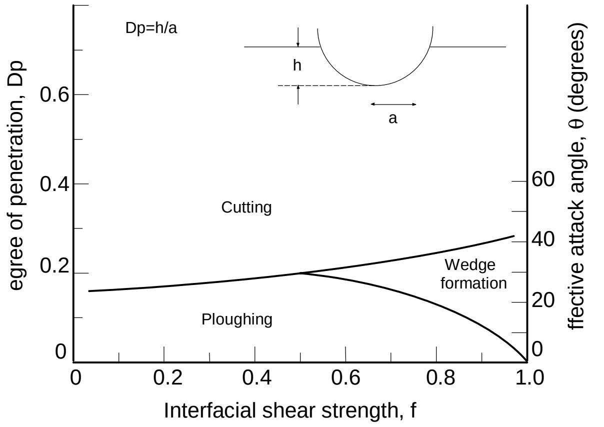

Figure 2. Modes of deformation observed in the sliding of a hard spherical indenter on α-brass, plain carbon steel (0.45% C) and an austenitic stainless steel (AISI 304), Hokkirigawa et al., 1988 (after Hutchings, 1992).

The mode of sliding depends on the force (normal load), radius of the indenter, and shear strength of the contact. According to the experimental results at low speeds, the transition from one mode of sliding to another depends on the lubrication. For experiment in Hokkirigawa et al. (1988) the load was about 0.7N and the radius of the indenter 27μm (and 62μm).

This above graph (figure 2) shows the condition at the rake face at the start of cutting. For example if there is complete adherence the cut starts when the attack angle is higher than 40 degrees, or degree of penetration is 0.3. When there is perfect lubrication however, the degree of penetration necessary to start cutting is less than 0.2.

In this experiment an interesting result was obtained that over a certain value of Dp the coefficient of friction is the same for both conditions, lubricated or dry.

The contact length could be estimated if the value of the forces acting on the contact is known. Direct measuring of the load F in cutting is not possible because it will be necessary to adjust the depth of cut to the minimum value, which is unknown. However there are other methods to estimate this force. Supposing the contact does not depend on feed rate it is possible to measure this force for various feeds and then extrapolate back to zero feed rate as in Chu (1998). Gordon (1967) used a split cutting tool device to measure and separate the forces acting on the rake face and flank face, but some extrapolation is still needed for values close to the cutting edge.

3.EXPERIMENTAL WORK

The machining process used was external turning of an AISI1040 rolled steel with an average hardness of 199Hv. The composition of the material was:

0.43%C 0.83%MN 0.19%Si 0.035%S 0.007%P 0.19%Cu 0.11%Ni 0.14%Cr 0.05%Mo 0.027%Al 0.04%Ti

The tool was cemented carbide designated ISO M35 with a TiN-TiC-TiN coating. It has geometry given by SNMG 120404. When mounted in the tool holder the approach angle was 45 degrees, the rake angle was 5 degrees, the clearance angle 5 degrees and zero inclination of the cutting edge. This tool has rounded cutting edges with a radius of 0.0425mm measured in the optical microscope.

Three cutting speeds were used: 22, 30, and 40m/min. Cutting forces are measured for several feed rates (0.005, 0.01, 0.02, 0.03, 0.04, 0.05, 0.10, 0.15mm/rev) and then extrapolated to zero feed. These cutting speeds are in the region of BUE formation (for the highest feed rates), which could affect the extrapolation, however at low feed rates there is no BUE.

4.RESULTS AND DISCUSSION

The results of the force measurements (cutting force and feed force) and the curve used to fit them are shown in figure 3, as well as the correlation factor, which is very good, for each curve.

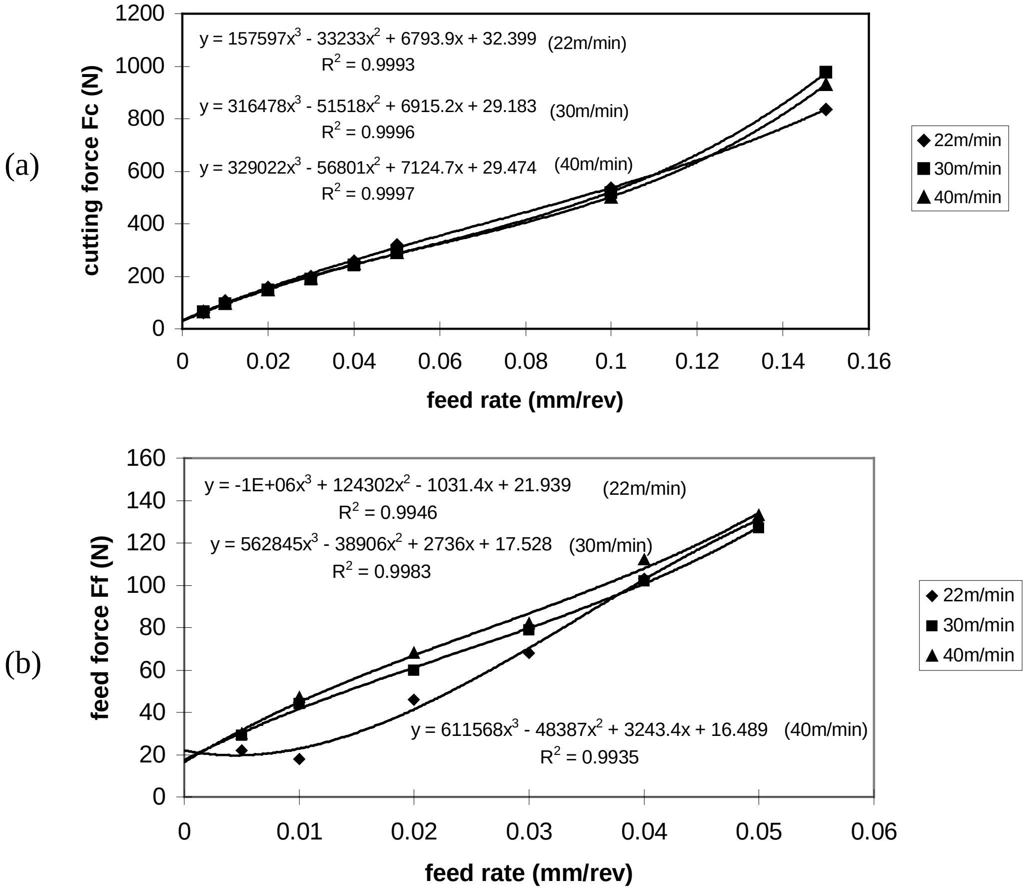

Figure 3. Residual cutting forces. a-cutting force Fc, b-feed force Ff.

According to these graphs the following residual forces are obtained:

Vc (m/min)	Fc (N)	Ff (N)
22	32	23
30	29	25
40	29	31

Feed force is the result of the measurement but resolved in the direction of the chip flow, which means the extrapolated value divided by sin(45º).

In the case of zero feed rate, the movement of the tool against the workpiece can be considered as a mechanism of metallic friction. The force required to move the slider (tool) is considered to be the force to shear the junctions that form between the surfaces and the force necessary to displace the material of the workpiece from the front of the tool, Bowden et al. (1958).

According to the theory, the ploughing force depends on the width of the track. In the case of machining the width of the cut is the depth of cut, or the length of the cutting edge that is in action.

Wallbank (1978) measured a contact length of approximately 0.180mm for mild steel and dry conditions using a special quick stop device where the tool moves horizontally. The minimum depth of cut for a contact length of 0.180mm is approximately 10μm. This value is obtained by the geometry of the tool. The area of contact is then approximately 0.6mm^2, which gives a normal stress of 42N/mm^2 (25/0.6). Considering Young's modulus of 20x10^{4}N/mm^2 for steel, the engineering strain causing such deformation should be in the order of 10^{-3}. The same calculation for all conditions indicates an engineering strain between 10^{-4} to 10^{-3} (the strain at the limfit of proportionality in a normal tension test is of the order 3x10^{-3} for steels), depending on the cutting speed. This suggests that a minimum depth of cut of 10μm (generating a contact on the flank face of 0.180mm) could well be elastic deformation of the workpiece.

For the static situation, the theory predicts that plastic deformation begins when the mean pressure is 1.1Y, where Y is the uniaxial yield stress of the material. This value is about 350N/mm^2 for the AISI1040. Assuming that cutting will start at the onset of plastic deformation the results of the tests gives very high values for the mean pressure to start chip formation.

Form et al. (1970) consider that there will be a contact length below the cutting edge on the flank face, but this contact is formed by a dead material that adheres and envelopes the cutting edge. This dead material is similar to a BUE extended to the flank face. He suggests that the new surfaces (machined surface and chip) are formed by cracks that initiate at the extremity of this dead zone which have to exist independent of the cutting conditions, otherwise separation of material is not possible. In the experiments of Wallbank (1978) using a horizontal quick stop, there is no sign of fracture on the contact band, which would be expected if the contact is formed by dead zone of material adhered to the tool. However this can be a mechanism of formation of the surfaces when there is BUE. Depending on the shape of the BUE formed it can extend into the workpiece, changing the tool edge geometry (edge rounding) and avoiding contact between machined surface and tool.

To calculate the contact length using expressions for the static situation it is assumed that when pressing the tool against the material the contact will persist when the tool starts to move. At this point it is interesting to recall that the hardness indentation will leave a mark in the material that depends on the ductility. For example, if we use a pyramidal indenter the shapes shown on figure 4 are possible, and the last one are typical of ductile materials.

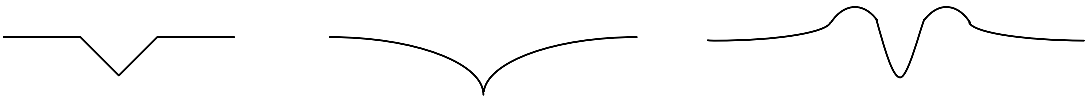

Figure 4 Exaggerated shapes left on the material by a pyramidal indenter, Dieter (1976).

If this could persist when the indenter moves, the contact length on flank face will certainly be higher than the ones obtained by the theoretical calculations.

In the experiments of Sedricks (1963) to simulate the abrasive process, a pyramidal indenter was used as the tool. It was observed that the normal force is supported just by the friction of the chip with the rake face and therefore no contact with the flank face. The contact existed just for the static situation.

Assuming that it is true that the tool has to penetrate a certain depth to start to cut material and that the residual forces represents the forces acting on the cutting edge just before the cut starts it is possible to give experimental evidence of this critical penetration. In the graph of cutting force against time, the time necessary for the force to reach the mean value (and oscillate around it), represents the time since the tool first touches the surface until it is removing material at a constant undeformed chip thickness. As an example, the graph of figure 5 presents the behaviour of cutting force against time for Vc=22m/min and f=0.001mm/rev, for the same material and depth of cut used in this work.

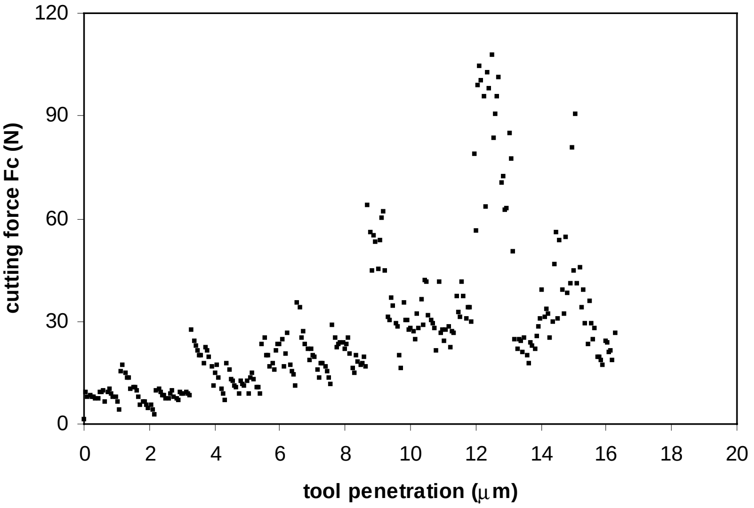

Figure 5. Cutting force against time, 22m/min, 0.001mm/rev.

The diameter of the workpiece was 180mm, which means that the angular speed was 39rpm. The feed speed is therefore 0.04mm/min, or 0.0007mm/s. It takes about 13s for the force to reach the mean value. The force in this graph was measured at a frequency of 12 s^{-1}. At this frequency and for the feed speed it means that the force was measure every time the tool travelled 0.05μm in the direction of the feed. According to the graph the value of 32N, which is the residual cutting force for 22m/min, is reached when the tool had penetrated more than 9μm. This value is very close to the one that would give a contact length on the flank face of 0.18mm.

If this contact persists unchanged during the cut, it will generate heat to increase the temperature of the workpiece and tool. Part of the heat generated on the primary shear plane to form the chip is dissipated into the workpiece increasing its temperature. After forming the chip, there is the contact with the tool flank face and heat generation, and a further increase in the workpiece temperature will be seen. Therefore, when using the relationship to calculate the temperature of the workpiece due to heat coming from the primary shear plane, like the one proposed for Boothroyd et al. (1989), another term due to the contact with the flank face has to be added.

5.CONCLUSIONS

This works shows some evidence for contact between machined surface and tool flank face. Direct measurement of this contact is very difficult, if not impossible, but it seems reasonable to expect that it will happen in machining. There is some experimental evidences that indicates the proportion of the contact, which could be due to elastic recovery of the material.

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