

Analysis of Burr Formation Mechanism in Turning Aluminum Alloy Al6061-T6

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Abstract

The paper represents an experimental study of the burr formation mechanism in feed direction. The influence of tool angles and workpiece angles, as well as and other cutting conditions on burr dimensions is considered. The work contains experimental graphs of burr cross-sections obtained using a laser measurement system at various stages of burr formation. The analysis of the experimental work shows that, depending on the cutting conditions, a few mechanisms of burr formation can be distinguished. The study could be useful in the search for optimal tool geometry for burr minimization and for the modeling of a burr formation mechanism.

INTRODUCTION

The presence of burrs on the edges of parts is the cause of various problems in manufacturing. Consequently, the deburring processes are included in manufacturing, which increase the production cost and require a significant amount of time. The selection of an appropriate deburring method depends on the dimensions and the location of the burr. Thus burr sizes must be controlled for the optimal choice of a deburring process or cutting parameters for burr minimization. One of the ways to solve this problem is to make analytical models of burr formation processes. However this approach requires a clear understanding of burr formation mechanism, which can be attained by experimental observations of burr development processes.

The burrs formed in feed direction normally have the largest dimensions and therefore cause bigger problems in deburring. The existing studies of these burrs [1 - 6] are mostly concentrated on final burr geometry whereas the direct observations of burr formation process have not been deeply investigated. As a result, the mechanism of that process remains unclear. It concerns the determination of the nature of forces causing burr formation, combined influence of tool and workpiece geometry, and other cutting conditions.

This paper is devoted to the study of some aspects of the burr formation process in turning of aluminum alloy Al6061-T6 when tool is unworn. These are comparatively simple machining conditions. However, if we understand the burr formation mechanism in the simple case and can model it, then we can describe burr formation mechanism by applying reasonable assumptions to more complicated cases.

EXPERIMENTAL SETUP AND PROCEDURE

The experiments on burr formation were carried out on a CNC turning machine tool. The experimental setup, tool and burr geometry are shown in Fig.1. The length L of the workpiece was controlled for every experiment in order to prevent significant vibrations which in turn causes specific noise, worsens surface roughness and changes burr dimensions.

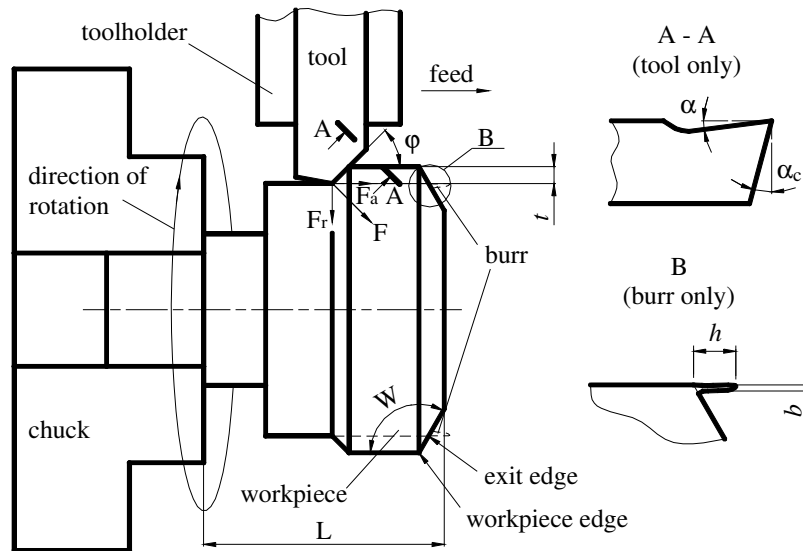


Fig. 1. Experimental setup

K10 grade of tungsten carbide-cobalt alloy was chosen as a cutting tool material. Short-time cutting of Al6061-T6 does not lead to significant wear of this tool material, and experiments can be considered as cutting by perfectly sharp tool. Table 1 presents tool geometry used in the experiments, and Table 2 lists the cutting conditions.

Table 1. Tool geometry used in experiments

Rake angle α [°]	Clearance angle α_c [°]	Lead angle φ [°]	Inclination of major cutting edge [°]	End cutting-edge angle [°]	End relief angle [°]
-5, 0, +5, +10, +20	5, 10, 15, 20	16, 32, 47, 66, 81	0	5	5

Table 2. Constant conditions used in experiments

Cutting speed v (m/min)	Feed f (mm/rev)	Depth of cut t (mm)	Workpiece angle W (°)	Rake angle α (°)	Clearance angle α_c (°)	Inclination of major cutting edge (°)	End cutting-edge angle (°)	End relief angle (°)
800	0.1	1	90	0	10	0	5	5

Components of the cutting force were measured using a dynamometer. Burr height h and burr thickness b (see Fig. 1) were measured after every experiment using the laser measurement system [7]. Special experiments were executed to allow observation of the burr formation process. The machining was stopped at various distances from the exit surface, starting from the point when the tool major edge reaches the workpiece edge. The burr formed at each stage was scanned using the laser measurement system along the two surfaces which form the workpiece edge. The two graphs obtained from the scanning of those surfaces were combined to get a cross-section of the burr. This process was done for each step until the burr was fully formed. Using the described method, the development of burr was observed for various cutting conditions.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Determination of forces that cause burr formation

It is known that decreasing the clearance angle leads to the increase of forces on the clearance face, while an increase of the rake angle causes the reduction of forces acting on the tool

rake face. Fig. 2 shows that the clearance angle does not have any significant influence on burr dimensions, but increasing the rake angle does cause their considerable reduction.

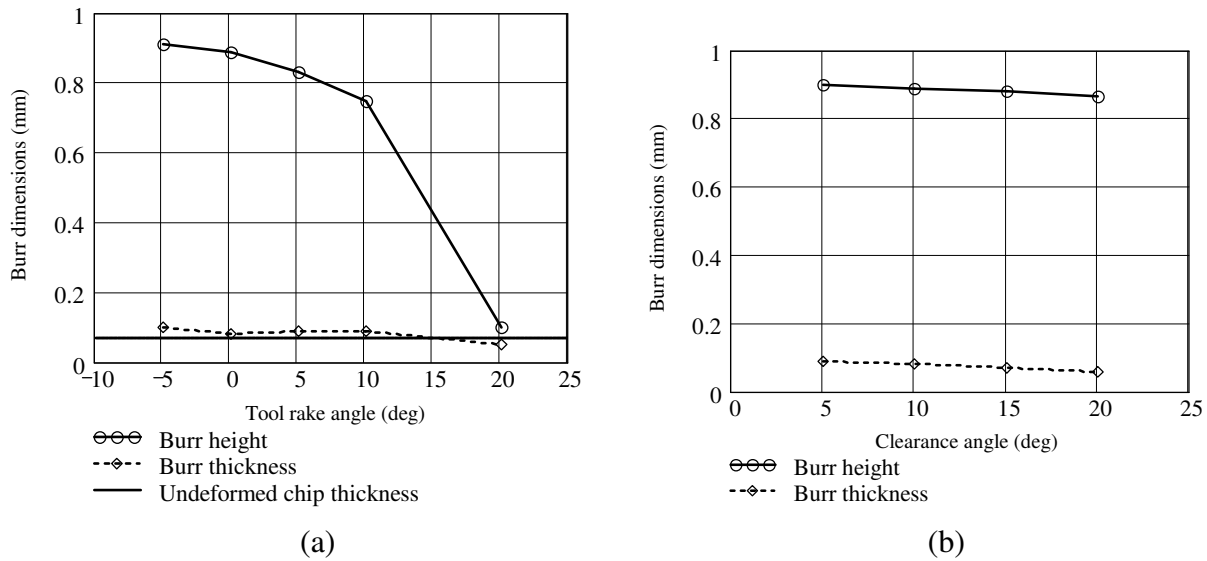


Fig. 2. The influence of tool rake angle (a) and clearance angle (b) on burr dimensions (cutting conditions: (a) $\alpha_c = 10^\circ$, the rest as in Table 3; (b) $\alpha = 0^\circ$, the rest as in Table 2).

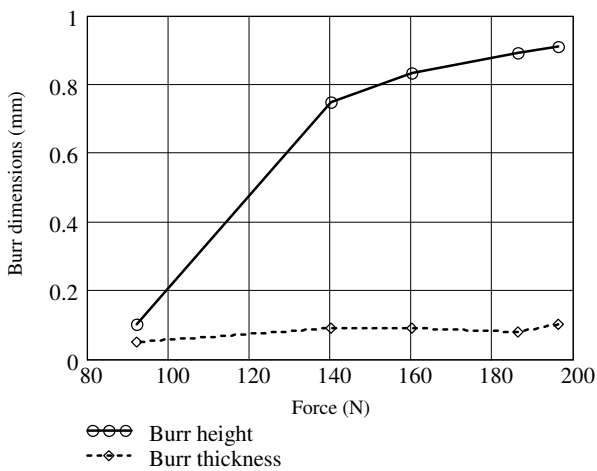


Fig. 3. Burr dimensions vs cutting force F (conditions are the same as in Fig. 2(a)).

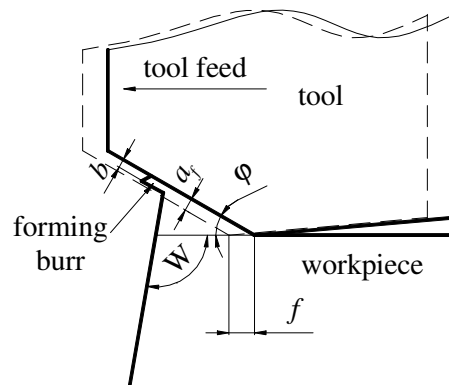


Fig. 4. Scheme of a burr being cut off.

Indeed the stresses that arise as a result of chip formation are more significant than those under the tool clearance face. Cutting of photoelastic celluloid [8] shows that the stress field which appears ahead of the tool spreads deeper below the cutting surface than that which arises under the clearance face. This proves that stresses in the shear plane are more considerable than those under the clearance face. Thus the formation of feed-burr is caused by the stresses that arise in the chip formation zone. Furthermore, the depth of the stress field that arises ahead of the tool is greater when the tool rake angle is smaller [8]. The depth of that field is most likely interrelated with the burr thickness and this explains the decrease of burr thickness when the rake angle increases. This phenomenon can also be related to the cutting force F that is a sum of radial F_r and axial F_a components of the cutting force (see Fig. 1). Figure 3 shows that burr dimensions grows almost in a linear fashion as cutting force F increases, except for the rake angle 20° when burr formation mechanism is changed. This situation is schematically described in Fig. 4. The undeformed chip thickness a_f is related to the tool feed f and lead angle ϕ as

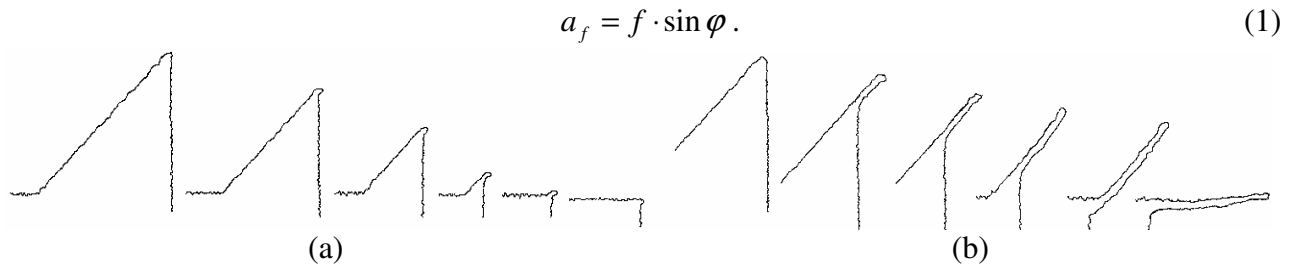


Fig. 5. Burr formation when rake angle (a) $\alpha = 20^\circ$, (b) $\alpha = 0$ [$\varphi = 47^\circ$, the rest as in Table 2].

If the undeformed chip thickness a_f exceeds thickness b of the forming burr (see Fig. 2(a)) then the burr cuts off and renews with each revolution on the workpiece (see Fig.5(a)), resulting in a burr of a small height. For rather low rake angles, the burr length increases with each revolution of the workpiece (see Fig. 5(b)) since the burr thickness is higher than the parameter a_f in this case (see Fig. 2(a)).

Influence of rigidity angle

The rigidity of the topmost part of the allowance defines by the angle $W - \varphi$. Fig. 6 represents the influence of this angle on burr height for various lead angles. For all lead angles, the increase of the rigidity angle leads to the rapid decrease of burr height, and under the certain value of the rigidity angle the burr does not form. The influence of the rigidity angle on burr formation mechanism was experimentally studied for the particular value of the workpiece angle $W = 90^\circ$ and is presented in Figs. 5 and 7 for the conditions listed in Table 2.

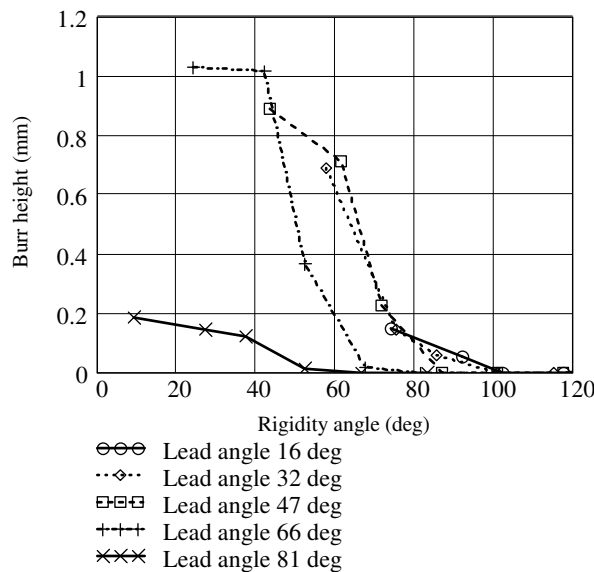


Fig. 6. Burr height vs. rigidity angle when cutting with tools of various lead angles (other cutting conditions as in Table 2).

In cases when the rigidity angle is rather high, burr formation starts when the tool major cutting edge reaches and goes beyond the workpiece edge. In this state, the top of the uncut part becomes weak and the stresses exerted by the tool tend to deform sideward the topmost part of the allowance. When the rigidity angle is 74° (see Fig. 7 (a)), this deformation is most likely caused by the lateral flow of material. In this case, the burr is so thin that it is removed by the next revolution of the workpiece, and each revolution of the workpiece produces a new side burr of the same size. This mechanism seems to be similar to that one shown in Fig. 5(a).

When the rigidity angle becomes lower, as 58° (see Fig. 7 (b)), bending becomes a predominant factor in the burr formation mechanism. In this case, with every revolution of the

workpiece a new portion of material bends sideward extending the burr formed during the previous revolution. However, the extent of bending of the previous burr allows some portion of the material at the top of the burr to be cut off during the next revolution of the workpiece. This results in a burr whose height is smaller than the depth of cut t .

When the rigidity angle is 24° (see Fig. 7 (c)), the stresses that arise due to cutting result in the pure bending of the remaining part of allowance without cutting off the tip of the burr. Consequently, the burr height h is equal to the depth of cut t in this case.

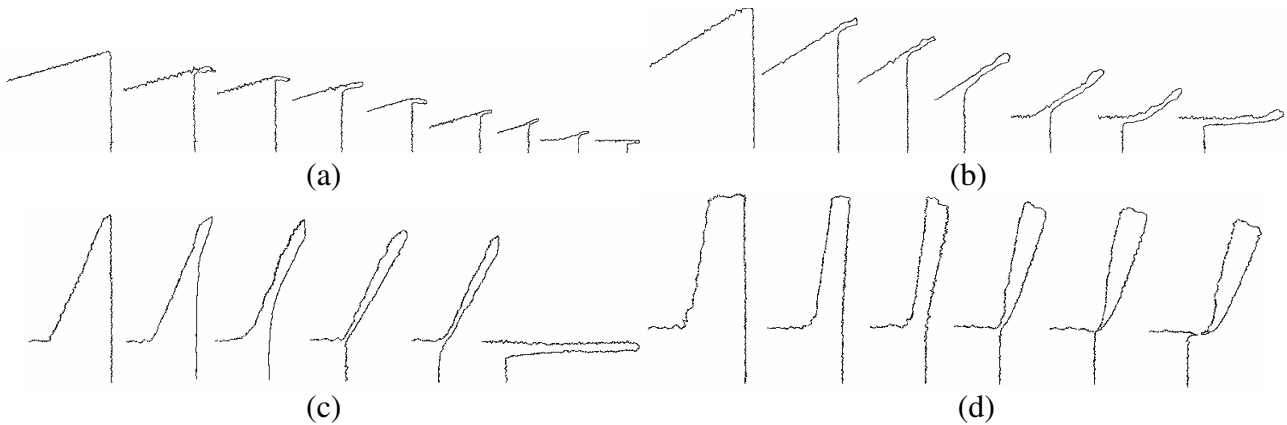


Fig. 7. Stages of burr formation [(a) $\varphi = 16^\circ$, (b) $\varphi = 32^\circ$, (c) $\varphi = 66^\circ$, (d) $\varphi = 81^\circ$].

When the rigidity angle is small, say 9° (see Fig. 7 (d)), the formation of a burr starts before the tool major cutting edge reaches the workpiece edge. After the burr starts forming, the removal of the remaining part of allowance takes place close to the tool tip because the material has sufficient rigidity to allow cutting only in this area. As a result when the tool tip reaches the exit edge, the remaining part of the material becomes progressively thinner in this zone, and the final step of burr formation is accompanied by a shearing of the work material resulting in a burr of a small height h .

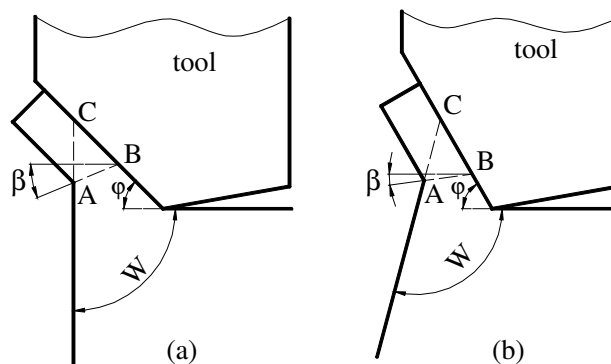


Fig. 8. Change of the direction of the favorable deformation for the same rigidity angle.

However, the rigidity angle is probably the factor determining the burr formation mechanism for one tool pass but not the final burr dimensions since for the same value of this angle the burr size can be different (see Fig. 6). Using the solution to the problem of plastic bending of a wedge exerted by uniform pressure [9], we can assume that the deformation field of the remaining part of allowance in the cross section is restricted by line AB of isosceles triangle ABC as shown in Fig.8. Angle β characterizing the direction of deformation can be obtained geometrically as

$$\beta = 90^\circ - \frac{\varphi}{2} - \frac{W}{2}. \quad (2)$$

Subsequently, even though angle $W - \varphi$ remains constant, angle β can be different, as is shown in Fig.8. Furthermore, the smaller β makes it more probable that the burr will be sheared at the final stage as in Fig. 8(b), resulting in a small burr. The larger β tends to lead to bending of the material, and in this case a larger burr can be expected.

CONCLUSION

The mechanism of burr formation in feed direction when cutting aluminum alloy Al6061-T6 using a sharp tool depends essentially on tool geometry, workpiece angle, and feed. The mechanism is determined mainly by the stress state in the chip formation zone, though stresses on the tool clearance face have a very slight influence on burr formation.

The rigidity of the remaining part of allowance, describing by the angle $W - \varphi$, determines the burr formation mechanism for a single tool pass. When this rigidity factor is high, the formation of the burr is caused by the lateral flow of material under normal pressure, producing small sideward burr. When the rigidity angle φ becomes low, the formation of burr occurs due to the bending of the uncut part of allowance. For the very low angle $W - \varphi$, the final stage of burr formation is accompanied by shearing of the uncut part of allowance resulting in a burr of small height. Further experimental observations should be done to clarify the influence of angle β on the final stage of burr formation.

If the thickness of the burr b is less than undeformed chip thickness a_f , then the burr is cut off and re-occurs with each revolution of the workpiece. If the thickness of the burr b exceeds undeformed chip thickness, then the height of this burr extends with each turn of the workpiece.

The investigated mechanisms of burr formation are probably common for all materials which plastic properties are similar to those of aluminum alloy Al6061-T6. For rather brittle materials, the considered burr formation mechanisms might not be applicable since the deformations occurred in burr formation should lead to the brittle failure of the burr.

Further studies should be focused on the search for optimal tool geometry that can effectively minimize burr size or prevent its formation altogether and satisfy the limitations of tool performance. The results of this research will be also useful for subsequent studies and for the modeling of burr formation mechanism in feed direction for face milling and drilling in order to find optimum conditions where burr dimensions can be predicted and controlled.

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References

- [1] K. Nakayama, M. Arai: *Annals of the CIRP*, Vol. 36 (1987), No. 1, pp. 33-36.
- [2] K. Takazawa, S. Xiong, K. Kitajima, T. Miyake, Y. Tanaka: *Proc 3rd International Conference "Precision Surface Finishing and Burr Technology"*, Seoul, (1994), pp. 232-245.
- [3] N. A. Lukoto, Z. Katz: *Proc of 7th International Conference on Deburring and Surface Finishing*, University of California, Berkeley, (2004), pp. 17-28.
- [4] J. Kim, D.A. Dornfeld: *Transactions of NAMRI/SME*, Vol. 28 (2000a), pp. 317-322.
- [5] A.K. Kaminise, R.A. Goncalves, A.R. Machado, M.B. de Silva: *Proc of 7th International Conference on Deburring and Surface Finishing*, University of California, Berkeley, (2004), pp. 127-136.
- [6] S.-L. Ko, J.-K. Lee: *Journal of Materials Processing Technology* 113 (2001) 392-398.
- [7] S.-L. Ko: *Proc 6th International Conference "Precision Surface Finishing and Deburring Technology"*, St.-Petersburg, (2000), pp. 109-123.
- [8] T. N. Loladze: *Chip Formation in Metal Cutting (in Russian)* (Mashgiz, Moscow 1952).

[9] L.M. Kachanov: *Fundamentals of the Theory of Plasticity (in Russian)* (Science, Moscow 1969).