Available online at www.sciencedirect.com

SCIENCE DIRECT®

International Journal of Machine Tools & Manufacture 45 (2005) 1015–1022

INTERNATIONAL JOURNAL OF MACHINE TOOLS & MANUFACTURE DESIGN, RESEARCH AND APPLICATION

www.elsevier.com/locate/ijmactool

Experimental study of burrs formed in feed direction when turning aluminum alloy Al6061-T6

Andrey Toropov[1], Sung-Lim Ko*, Byung-Kwon Kim

School of Mechanical and Aerospace Engineering, Center for Aerospace Systems Intergration Technology (CASIT) Konkuk University, 1 Hwayang-dong, Kwangjin-gu, Seoul 143-701, South Korea

Received 7 July 2004; accepted 30 November 2004
Available online 28 January 2005

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 discerned: sideward burr formation, bending of the uncut part of allowance, and the shearing of residuary material at the final stage. This study could be useful in the search for optimal tool geometry for burr minimization and for the modeling of a burr formation mechanism.

Keywords: Burr; Feed direction; Turning

1. 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. The additional deburring operations increase the production cost and these additional expenses may contribute up to 30% of the total product price [1]. Furthermore, deburring normally requires a significant amount of time. This, coupled with the deburring cost, increases as the amount of burrs rises.

Presently, about 100 deburring methods have been developed [2]. 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 accumulate the experimental data about burrs and then to develop expert system using the compiled database. The other way is to make analytical models of burr formation processes. However the latter method requires a clear understanding of burr formation mechanism which is based on experimental observations of burr development processes.

Significant success in this field has been achieved in the study and modeling of burr formation in orthogonal and oblique cutting [3–7]. However, the burrs formed in feed direction normally have the largest dimensions and therefore cause bigger problems in deburring. There are many research papers devoted to the study of burr formation in feed direction [8–12]. However the existing studies are mostly concentrated on final burr geometry whereas the direct observations of burr formation process have not been investigated. The application of cinematic techniques [8] and acoustic emission technique [9] did not provide any data about variation of burr cross-section during burr formation. The so-called ‘destructive method’, applied to the observations of burr formation in drilling [12], cannot be used for small sensitive burrs since it can damage the burr, resulting in incorrect burr form. The burr measurement system [13] used in this study is based on the scanning of the workpiece edge by a laser. This method provides data with satisfactory

* Corresponding author. Tel.: +82 2 450 34 65; fax: +82 2 447 58 86.
E-mail addresses: andrey@konkuk.ac.kr (A. Toropov), slko@konkuk.ac.kr (S.-L. Ko).
[1] Tel.: +82 2 450 41 94.

0890-6955/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2004.11.031

reliability without any destruction of work material, and the combination of two graphs obtained from scanning the two surfaces which form the workpiece edge gives the real view of burr form in cross-section.

In spite of significant success in studying burr formation in feed direction, the mechanism of that process remains unclear. It particularly concerns the determination of the nature of forces predominant in the process. Two kinds of forces can cause burr formation: those acting on the tool rake face and those acting on the clearance face. Determining the prevalent forces is an important aspect since it would provide the basis for burr modeling and would help to control burr formation processes. The influence of tool lead angle has also been studied insufficiently despite the significant influence of that parameter on burr dimensions. The same can be said of the combined influence of workpiece and lead angles.

This paper is devoted to the study of the burr formation process in turning. Turning is a comparatively simple machining operation. 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 such as face milling and drilling.

The paper considers the case of burr formation when tool is unworn. Short-time cutting of aluminum alloy Al6061-T6 by tungsten carbide tool does not produce any significant tool wear. Thus the experiments can be regarding as a cutting using a perfectly sharp tool. Besides, aluminum alloy Al6061-T6 is one of the widespread work materials which plastic properties are sufficient to allow complete burr formation in feed direction without brittle failure of a burr. These points determined the choice of tool and work materials for the given experimental work.

2. 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.

K10 grade of tungsten carbide–cobalt alloy was chosen as a cutting tool material. Al6061-T6 belongs to the group of silicon aluminum alloys. According to the classification [14], K10 grade is recommended for turning, milling, drilling and boring of silicon aluminum alloys, and thus it is suitable for the given experiments.

Table 1 presents tool geometry used in the experiments, and Table 2 lists the cutting conditions. The cutting conditions were selected in order to exclude built-up-edge formation in experiments.

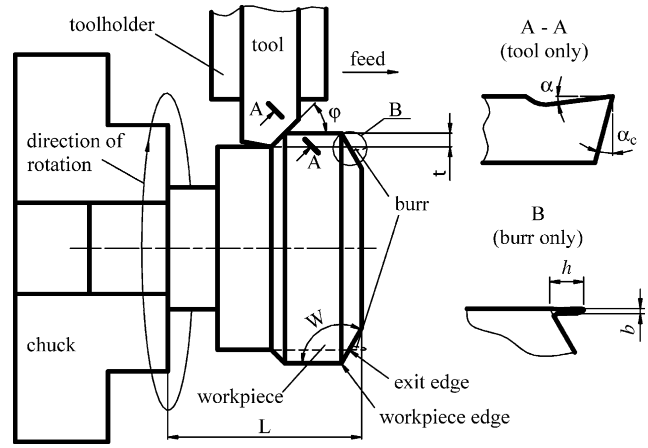

Fig. 1. Experimental setup, tool geometry and final burr dimensions.

Burr height h and burr thickness b were measured after every experiment using the laser measurement system [13] as shown in Fig. 2, and average values of burr dimensions were calculated. Burr dimensions b and h are shown in Fig. 1. Special experiments were executed to allow observation of the burr formation process. The essence of the method is as follows. 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 all lead angles listed in Table 1. The cutting conditions used in these experiments are listed in Table 3.

3. Experimental results and discussions

3.1. Influence of lead angle

Fig. 3 shows the influence of the lead angle ϕ on the burr dimensions for the cutting conditions listed in Table 3. The stages of burr development for those conditions are presented in Figs. 4–6. The experimental data show that burr formation mechanism depends significantly on the lead angle.

For small lead angles, the formation of the burr is most probably related to the formation of sideward (or Poisson) burr comprehensively investigated by Nakayama and Arai [3]. When the major tool cutting edge and machining surface form an angle of $180° - \phi$ as shown in Fig. 7(a), the formation of side burr is not possible because of the high rigidity of material. When the tool major cutting edge reaches and goes beyond the workpiece edge, this angle becomes $W - \phi$. Fig. 7(b) shows this situation when $W = 90°$