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Experimental observation and analysis of burr formation mechanisms in face milling of aluminum alloys

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Abstract

The purpose of this paper is to study the burr formation mechanisms in face milling process, and to investigate the influence of cutting conditions on burr formation in face milling of aluminum alloys. The fly milling cutter is used to carry out single-tooth face milling tests. Three aluminum alloys were tested: Al 1100 (cold drawn), Al 2024-T4 and Al 6061-T6. It is found that the burr geometry is strongly dependent upon the in-plane exit angle. Five types of burrs were observed in the experiments: knife-type, wave-type burr, curl-type, edge breakout and secondary burr. Formation mechanisms of each type of these burrs are discussed in details. The relationship between their existence and the machining condition is indicated. The machining guideline in face milling is given at the end of the paper to reduce burr size effectively through the formation of secondary burr.

Keywords: Face milling; Burr formation; Edge breakout; Exit angle; Secondary burr

1. Introduction

Undesirable burrs are created in most machining processes. A burr is a plastically deformed material that remained on the workpiece after machining. It is often in the form of a rough strip of metal at the edge of the workpiece adjacent to the machined surface. The burrs produced on piece part edges in machining operations must be removed for most parts to function effectively. The existence of burrs on a workpiece may cause several problems, such as: decreasing the fit and ease of assembly of parts; damaging the dimensional accuracy and surface finish; increasing the cost and time of production due to deburring; jeopardizing the safety of workers and consumers; contributing to electrical short circuits; reducing cutting performance and tool life; and degrading the aesthetics of the components. Burrs are injurious even during machining because they hit the cutting edge and cause groove wear. This groove wear, in turn, accelerates the burr growth [1].

The removal of burrs or deburring is often done by additional machining with abrasive or finishing tools. While manual deburring is a workable solution, it has several limitations. It is tedious, time consuming and yields unpredictable and inconsistent results. Special precautions must be taken to ensure the safety of workers in a manual deburring cell. A manual deburring operation can also be a bottleneck in a production line. Deburring is especially necessary in the manufacturing of precision parts such as computer components or aircraft engine parts. For example, in the computer storage manufacturing industry, an attached burr may inhibit assembly of the file, or a detached burr may later restrict file function or cause disk crash [2]. In the case of engine parts, producing a turbine blade with a specific contour is necessary to reduce the local stress intensity in the component and therefore to minimize the possibility of fracture [3].

Gillespie [4], a leader in this field, pointed out that burr technology is not simple. Deburring and edge finishing on precision components may constitute as much as 30% of the cost of the part and also can be the source of significant dimensional errors [5]. Progress in manufacturing has led to the need for improved deburring technology. Increased

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understanding of burr formation can yield tremendous befits in reducing the production costs [6]. It involves three key fields: burr formation modeling; sensory feedback for intelligent robot or machine to deburring control; and the automation of process planning to include cutter for burr minimization and a data base on burr experience [7]. In evaluating the requirements for deburring, the properties and characteristics of burrs produced by manufacturing process must be understood. The shape of burrs is highly dependent upon the particular manufacturing operation used. A burr can be a sharp ragged projection or it can be a small swell of raised material. In orthogonal cutting either burr or edge breakout (negative burr) can be formed where the tool exits the workpiece, depending on exit geometry and material condition [8]. In drilling process, an entrance burr forms as material near the drill undergoes plastic flow, while an exit burr is produced as a part of material extending out of the exit surface of the workpiece [9,10].

One positive aspect of burrs is that the location is generally predictable. In face milling operations, burrs can be expected to form on the edge where the cutter exits the workpiece. The purpose of this paper is to report the results of a study on the burr formation mechanisms in the face milling process, and to investigate the influence of cutting conditions on burr formation in aluminum alloy, especially the in-plane exit angle. Three aluminum alloys were tested: Al 1100 (cold drawn), Al 2024-T4 and Al 6061-T6. Five types of burrs were observed on the workpieces after machining: knife-type burr, wave-type burr, curl-type burr, edge breakout and secondary burr. Formation mechanisms of each type of these burrs are discussed in details. The relationship between their existence and the machining condition is indicated.

2. Burr classification and previous work review

Gillespie and Blotter [11] classified the machining burrs into four specific types: (1) Poisson burr; (2) roll-over burr; (3) tear burr; and (4) cut-off burr. This classification is based on the mechanism of their formation. The Poisson burr is formed as a result of lateral bulging of material along the work edge when it is compressed under a passing cutting tool. The roll-over burr is essentially a chip that remains attached to the work and pushed ahead of the cutting tool's path on exit from the work rather than being broken in formation. The tear burr is usually formed in a punching operation as the result of material deforming basically due to the tool/die clearance and, like the roll-over burr, adhering to the workpiece edge when the tool exits the part. The cut-off burr is a projection of material left when the workpiece falls from the stock before the separating cut has been completed.

Kishimoto et al. [12] conducted face milling experiments in normalized carbon steel S45C to investigate the burr formation in connection with cutting conditions and tool geometry. In their tests, two types of burrs were found and named as: (1) primary burr and (2) secondary burr. The primary burr is the roll-over burr produced on the tool exit edge. The burr thickness was found to vary from t_{min} (minimum burr thickness) to t_{max} (maximum burr thickness) along the length of the burr. They claimed that through proper selection of cutting condition and tool geometry, the roll-over burr produced during the face milling process will be separated at its thinnest portion and only a small burr will remain on the edge of the machined part. They named the former normal roll-over burr a "primary burr" and the latter one a "secondary burr" which is the material remaining after the breakage of the primary burr. The parameters investigated were the depth of cut, the exit angle, and the corner angle (inclination angle) of the tool, as shown in Fig. 1.

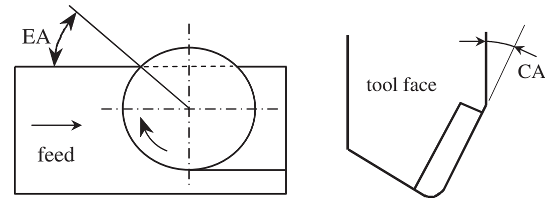

Fig. 1. Exit angle and corner angle [12].

Nakayama and Arai [1] approached the classification of machining burrs by: (1) the cutting edge which is directly associated with the burr formation; and (2) the mode and direction of the burr formation (backward or entrance burr, sideward burr, forward or exit burr, and leaned burr). By combining the two systems, burrs formed in various types of machining operations can be adequately designated. Olvera and Barow [13] studied the influence of cutting parameters on the formation of burrs in square shoulder face milling. Exit burr in the cutting direction, exit burr in the feed direction and burr formed at the top edge were discussed through their extensive experimental research. Chern [14] observed burr formation and edge breakout on the workpiece exit edge in orthogonal cutting and in face milling of aluminum alloys. Another study of burr formation was done by Lin [15]. He conducted a series of single-tooth face milling tests on stainless steel to study the burr formation and tool chipping. He found that the burr formation is close related to the chipping depth of tool edge. However, he did not explain the burr formation mechanisms clearly in his study. In this paper we would like to clarify the burr formation mechanisms in face milling, and to point out the relationship between their existence and the machining conditions. The machining guideline in face milling of aluminum alloys is then proposed in order to reduce burr size effectively.

3. Experimental equipment and method

Milling process is one of the most versatile and widely used metalworking processes. During the milling operation, burrs are created mainly where the milling cutter exits