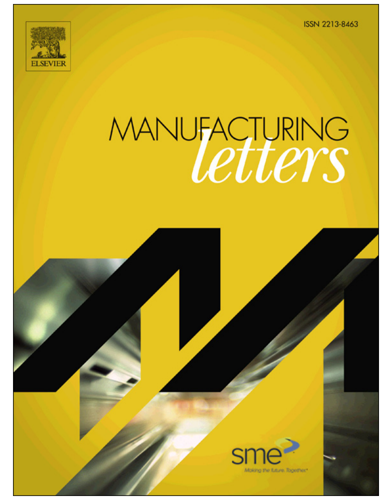

Letters

Recent Advances in Characterization, Modeling and Control of Burr Formation in Micro-Milling

Pankaj Kumar, Mohan Kumar, Vivek Bajpai, Nirmal Kumar Singh

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RECENT ADVANCES IN CHARACTERIZATION, MODELING AND CONTROL OF BURR FORMATION IN MICRO-MILLING

Pankaj Kumar, Mohan Kumar, Vivek Bajpai, Nirmal Kumar Singh
Department of Mechanical Engineering,
Indian Institute of Technology Dhanbad (JH) India

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Micro-milling, Burr characterization, Burr modeling, Burr control

ABSTRACT

The demands of high accuracy micro-parts and micro-scale features are increasing in the different industries today. Micro-milling is widely used to manufacture micro-scale parts and features. The major problem in the micro-milling operation is burr formation, as due to micro-scale size of burr, deburring becomes difficult. Burr deteriorates the quality and performance of micro-parts and features, therefore, burr minimization and control techniques are topics of extensive research today. Many researchers have worked on the micro-milling burr to achieve better control on the burr formation in micro-milling operation. This paper presents recent works on burr formation in micro-milling operation.

1. EXPERIMENTAL CHARACTERIZATION OF BURR FORMATION IN MICRO-MILLING

Smaller cutting area and feed per tooth to the radius of cutter ratio, size effect, minimum chip thickness, low stiffness of micro-tool, tool run-out etc. are such factors which distinguishes the micro-milling from the conventional milling operation. Due to smaller size of burr in micro-milling compared to conventional milling, burr removal and control is a big challenge. Cutting parameters, work-piece material properties, tool geometry, coating, lubrication are such factors which affect the burr formation in micro-milling operation.

Mian et al. [1] conducted micro-milling tests on wrought Inconel 718 nickel alloy work-piece and used acoustic emission (AE) signals to identify frequency/energy bands for understanding the size-effect mechanism. They found that feed per tooth to the cutting edge radius ratio was the dominant parameter in reducing the burr root thickness. More uniform and relatively larger burrs were found on the down milled side of all the slots. Biermann and Steiner [2] analyzed the top burr formation of austenitic stainless steel X5CrNi18-10 in slot micro-milling and concluded that up milling produces a significantly reduced top burr height. The top burr height increases with an increasing cutting speed due to the higher strain rate hardening of the material. Top burr height increases with increasing feed.

Saptaji et al. [3] observed the top burr formation of aluminum alloy Al-6061 in micro-milling to study the effect of side edge angle and taper tool angle on the top burrs in micro-milling. They concluded that the top burr in micro-milling is affected by both side edge angle and taper angle. The Combination of largest side edge angle and largest taper angle produces the smallest burr. Thepsonthi and Ozel [4, 5] used the process modeling and optimization methods to understanding the top burr formation of Ti-alloy Ti6Al4V in micro-milling. They found that the integrated toolpath strategy, axial depth of cut and feed rate are the major process parameters which affect the top burr formation and surface roughness. Higher feed rate results better surface roughness and channel quality. Cutting edge radius influences the burr formation in milling. Burr formation increases with the increase of cutting edge radius [6].

Wu et al. [7] investigated the influence of uncut chip thickness and cutting edge radius on burr formation of oxygen free copper in micro-milling operation. They concluded that the top burr decreases with the decrease of feed ratio and reaches its minimum value when feed ratio is equal to the cutting edge radius. Further, decrease in the feed ratio it results rapidly increase in the top burr. Smaller top burr was found in the up milling side compared to the down milling side. Mathai et al. [8] examined the burr formation of thin nickel-titanium alloy (nitinol) foil in micro-milling operation. They found larger down milling burr and three main shapes of burrs: rollover type, feathery type and wall type. Tool condition during the machining process affect the burr formation [9]. New tool and strong adhesive bond results smaller burrs at the higher feeds on either side of the groove. With a new tool, it was seen that spindle speed does not have a significant effect on the burr height but for a worn tool, lower spindle speed results larger burrs. A weak adhesive bond with the backing material also results larger burrs. Coating affect the burr formation in micro-milling [10]. Aslantas et al. [11] found reduced burr size in micro-milling with the coated tool.

Bajpai et al. [12] investigated the burr formation of titanium alloy Ti6Al4V in high speed micro-milling. They concluded that side exit burr in up milling side is the most critical and larger in all type of the burrs. Burr height decreases when spindle speed and feed increases. With the increase of depth of cut burr height increases. The burr width is only significantly affected by the depth of cut. Burr width increases with the increasing depth of cut (see fig. 1). The burr size do not alter significantly by the tool diameter and the number of flutes. Piquard et al. [13] studied the top burr formation of NiTi biomedical alloys in micro-milling. They found that feed per tooth and width of cut strongly affect the height and width of burr. Smaller burrs were found when feed per tooth increases and width of cut decreases. Thinner and wider burrs (with a characteristics curly shape) were obtained in up milling compared to down