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Optimization and Process Control in Small Diameter End Mill

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ABSTRCT

The recent technological progressions in industries have offered ascent to the continually growing requests for small structures, sensors, and parts. Small-milling is a promising method to create these scaled down structures, sensors, and parts. Yet, small-milling still confronts some significant difficulties, tormenting further provision of this innovation. The most noticeable around them is small burr formation. Burrs created along the completed edges and surfaces in small-milling operation have huge effect on the surface quality and performance of the completed parts and small structures. In any case, deburring of small-parts is not conceivable because of bad accessibility and tight tolerances in small segments.

One of the methods to minimize small burr formation in small milling is by enhancing the geometry of the device. As minimization of small burrs still remains a key test in small machining, not many researchers have worked in this field. The main aim of the research work is to present finite element analysis of flat end mill small cutters used in small milling by varying geometry of the tools. Apart from this, study has been done in detail on burr formation in small milling and what factors affect it. Burr formation simulation has been carried out while varying the tool geometry.
The outcome of the research will be a static finite element analysis of small burrs formed during small-milling which can help in determining tool life and a detailed dynamic analysis of small burrs formed during small-milling operation in Al6061-T6 which can benefit the aerospace industry in various ways. The results obtained during the analysis may be used for further research for burr minimization through tool optimization and process control.

Introduction

The fabrication of a wide variety of parts and products in various fields, like aeronautics, automotives, biomedical, medical and electronics requires proper finishing for proper mating and functioning of products. A variety of operations like milling, drilling, turning, grinding, EDM and water jet cutting are utilised to fabricate and finish parts. One of the most common and important form of machining is the milling operation, in which material is cut away from the workpiece in the form of small chips by feeding it into a rotating cutter to create the desired shape. Milling is typically used to produce parts that are not axially symmetric and have multiple features, such as holes, slots, pockets, and even three dimensional surface contours. Contoured surfaces, which include rack and circular gears, spheres, helical, ratchets, sprockets, cams, and other shapes, can be readily cut by using milling operation. Recently, small milling process has gained immense popularity due to market requirements and technological advancements which has lead to fabrication and use of small structures. It possesses several advantages like ease of use, capability to produce complex three dimensional geometries, process flexibility, low set-up cost, wide range of machinable materials and high material removal rates.

This chapter develops the background for the present work and discusses the need to take up this work. It presents a review of available relevant literature. Objectives of the present work along with methodology adopted to accomplish them are also discussed here.

Background

With the growth in technology, the expectations from products have greatly increased. More and more complex shaped parts of varying sizes are being designed, developed and used for a wide variety of industrial applications. The commercial success of a new product is

Motivation

Conventional milling has a wide range of industrial applications and is used where there is a requirement of complex shapes, removal of large amounts of material, and accuracy. However, with the advancement in technology, more and more industries are leaning towards the use and fabrication of miniaturized parts and products. In the present scenario, smallmachining is increasingly finding application in various fields like biomedical devices, avionics, medicine, optics, communication, and electronics. Among all small-machining operations, small-milling and small-drilling are the two most important operations.

Review of Literature

In direction of small cutting tools, researchers have approached few works related to modeling and analysis of small drilling (Cheong [1999], Hinds [2000], Kudla [2001], Endo [2006], Nakagawa [2007], Chen [2007], Kim [2008], Fu [2010], Zhang [2011], Aziz [2012]). In the field of small milling cutters, some work has been significantly explored. Bao et al. [2000] had presented a work discussing analytical modeling of small end mill cutters and tool run out. Vogler [2004], Jun [2006], Liu [2007] has worked on dynamic modeling and analysis of machining performance for surface generation and prediction of cutting forces in small milling. Three dimensional dynamic force model for small end milling have been investigated by Kang [2007], Li [2007], Filiz [2011], Li [2011]. Recently, Jun [2012], Wu [2012] & Mustapha [2013] have done the work related to cutting force and finite element modeling of small milling process.

Modeling and control of burr formation in both macro- and small- machining processes assumes a lot of significance. Gillespie [1976], Ko [1996], Chu [2000], Satish [2003], Alrabii [2009], etc. have discussed the burr formation and minimization in macro level. Besides, Kim [2004], Lee [2005], Liang [2009], Chang [2010], Lekkala [2011], Saptaji [2012], Chen [2012], Aziz [2012], etc. have also discussed small burr modeling, analysis and minimization.

Micro Milling Burrs

Burrs structured in processing and also small-processing operations are points of far reaching examination in light of the fact that these operations discover requisitions in passes on and molds utilized as a part of the injection molding of small fluidic gadgets, prototyping and assembling of energy components (small channels), generation of tubular parts in fluid filtration. A few requisitions in the fields of optics, gadgets, pharmaceutical, biomedical gadgets, correspondences and flying oblige without burr parts. Hence, demonstrating and control of burr arrangement in the smallmachining methods that produce small parts accept a considerable measure of centrality. On the other hand, it is noted that the all the small and in addition macro machining courses of action leave burrs on the machined parts. In the small-machining methodology, be that as it may, the burr is generally extremely troublesome to evacuate and, all the more vitally, burr evacuation can genuinely harm the workpiece. Accepted deburring operations can't be effectively connected to small-burrs because of the little size of parts. Likewise, deburring may present dimensional blunders and lingering burdens

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in the part. These issues are exceedingly subject to burr size and sort. Consequently, the best result is to avoid burr arrangement in any case. In the event that this is not plausible, a second approach is to minimize burr creation. For the usage of this methodology, it is discriminating to comprehend the essential systems included in burr development and the relationship between the cutting parameters, device geometry and burr phenomena.

Micro End Mill

Different machines and different types of cutters are used to perform small milling operations. Small milling cutters rotate about their axes and have surfaces containing equally spaced cutting. Small milling operation does not depend on work piece materials, dimensions and shapes. However, small mill cutters are very thin and cutter deflection and vibration may cause degradation of tool failure and accuracy. The calculations and formulae for determining speeds and feeds that work reasonably well for conventional mills require changes for use in the case of small milling cutters.

Flat and ball end milling cutters are the most common types of small milling cutters used for various operations. End mills have cutting teeth at one end as well as on the sides. These can be broadly categorized as being one of two types: Flat end mill cutters (Flat bottomed cutters) or Ball nose end mill cutters (Hemispherical-ended cutters).

They are usually made from HSS (High Speed Steel) or cemented carbide and can have one or more flutes.

Figure 4.1: Small end mills

Development of Three Dimensional CAD model of small flat end mill

The small end mill cutters used in this work are a two flute and a four flute flat small end mill cutter. Method involved in the design of a small end mill cutter includes:

- Creation of cross-sectional profile of the tool and helix generation
- Flute creation using slot operation
- Creation of back surface of the tool
- Cutting edge generation

Parameters involved in generating the cross sectional profile are:

- Rake angle of the tool
- Relief angle of the tool
- Tool diameter
- Number of flutes

Parameters involved in modeling the helix are:

- Height of the tool
- Diameter of the tool
- Pitch of the helix
- Helix angle of the tool

The three dimensional CAD models of both the flat end mills was produced by performing solid modeling in CATIA V6 environment.

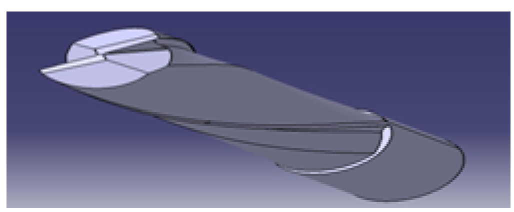

Figure 4.2: CATIA model of two flute small end mill

Analysis and Simulation

Once a three dimensional CAD model of small end mill cutter is developed, a no. of downstream applications can be performed, one of which is detailed finite element

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analysis and simulation of small end mill during small machining. Here, the static analysis of the small end mill and simulation of burr formation process in small milling has been carried out. In this work, tool material used is Tungsten Carbide (WC). Cemented carbides (WC-Co) are recently being used instead of tungsten carbides. Cemented carbide is a composite material containing a binder like cobalt (Co) which provides increased tool hardness.

The workpiece is a cuboidal block of aluminium alloy Al6061-T6 which is used in many aerospace applications. Al6061-T6 is a T6 tempered aluminium alloy containing magnesium and silicon as its major alloying elements.

Figure 5.1: Meshing performed on (a) two flute and (b) four flute small end mill

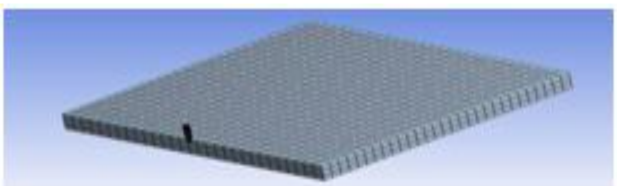


Figure 5.2: Meshing performed on the work piece

Static finite element analysis

Analysis

For static analysis at any particular instantaneous time, forces are considered on a single flute in feed direction (F_x), normal direction (F_y), and axial direction (F_z) for an axial depth of 0.2mm. The input forces for this analysis are obtained from the work done by Zaman et al. [2005] in which the analytical cutting force expressions developed in were simulated for a set of cutting conditions and were found to be comparable to experimental results..

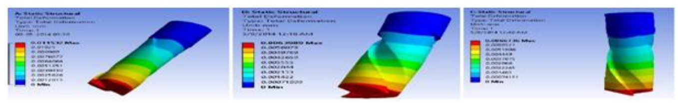
The applied forces in feed, normal and axial directions are F_x = 3.82 N, F_y = 4.01 N and Fz = -0.34 N.

Table 5.6: Cutting forces used as input

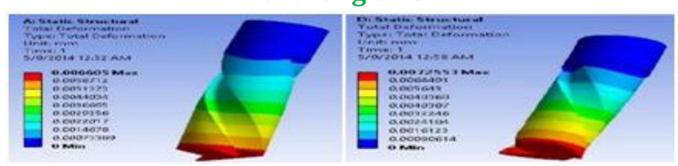
Force in feed direction (F_x)	3.82 N
Force in normal direction (F_y)	4.01 N
Force in axial direction (F_z)	-0.34 N
Cutting force applied (F_c)	5.548 N

Results

Figures 5.3 and 5.4 show the result for static analysis with deformed mesh and Von Mises stress respectively for the applied load for two flute flat end mill of diameter 0.3 mm.

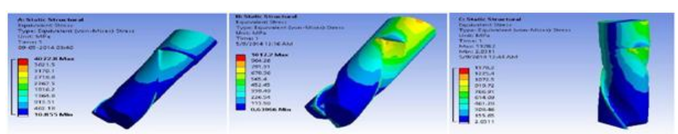


(a) Rake angle = 0º, Relief angle = 10º (b) Rake angle = -2º, Relief angle = 6º (c) Rake angle = 3º, Relief angle =8º



(d) Rake angle = 5º, Relief angle = 5º (e) Rake angle = 5º, Relief angle = 6º

Figure 5.3: Total deformation in the case of two flute small end mills



(a) Rake angle = 0º, Relief angle = 10º(b) Rake angle = -2º, Relief angle = 6º (c) Rake angle = 3º, Relief angle =8º

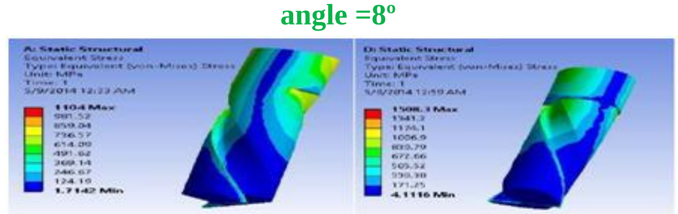


Figure 5.4: Von Mises stress in the case of two flute small end mills

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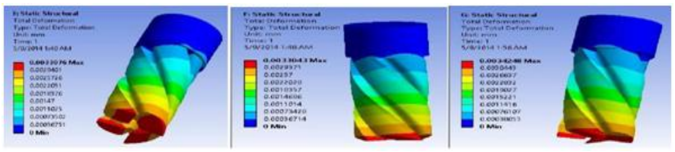
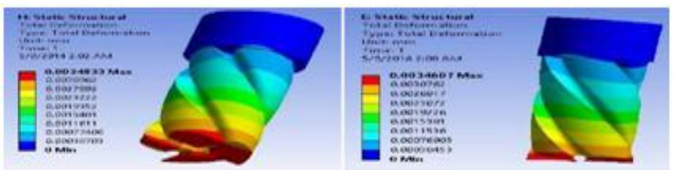
Figures 5.5 and 5.6 show the result for static analysis with deformed mesh and Von Mises stress respectively for the applied load for four flute flat end mill of diameter 0.3 mm.

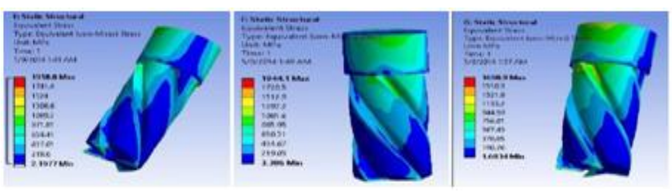


(a) Rake angle = 0º, Relief angle = 10º (b) Rake angle = -2º, Relief angle = 6º(c) Rake angle = 3º, Relief angle =8º

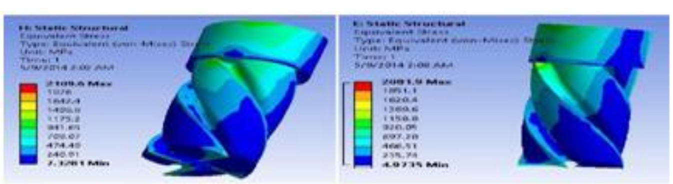


(d) Rake angle = 5º, Relief angle = 5º (e) Rake angle = 5º, Relief angle = 6º

Figure 5.5: Total deformation in the case of four flute small end mills



(a) Rake angle = 0º, Relief angle = 10º (b) Rake angle = -2º, Relief angle = 6º (c) Rake angle = 3º, Relief angle =8º



(d) Rake angle = 5º, Relief angle = 5º (e) Rake angle = 5º, Relief angle = 6º

Figure 5.6: Von Mises stress in the case of four flute small end mills

The results obtained are presented in Table 5.7.

Table 5.7: Results of static finite element analysis of small end mills

No. of flutes	Rake angle (degrees)	Relief angle (degrees)	Maximum total deformation (mm)	Maximum Von Mesis stress (MPa)
2	0	10	0.011532	1364.8
	-2	6	0.063989	339.49
	3	8	0.006736	461.28
	5	5	0.006605	369.14
	5	6	0.0072553	505.52
4	0	10	0.0033076	654.41
	-2	6	0.0033043	650.31
	3	8	0.0034248	567.43
	5	5	0.0034833	708.07
	5	6	0.0034607	697.28

From Table 5.6 it can be seen that a two flute small end mill cutter with rake angle -2º and relief angle 6º takes the least amount of Von Mises equivalent stress. In case of four flute small end mills, the least amount of Von Mises stress is taken by tool with rake angle 3º and relief angle 8º.

The deformation values shown in the above figures actually occur momentarily due to vibration of the cutter which is not taken into account during the analysis.

Dynamic finite element analysis and simulation of burr formation of two flute small end mill

Analysis

In order to observe burr formation and chip flow mechanism in a virtual environment, an explicit analysis has to be done on the tool and work piece interaction. In this paper, we

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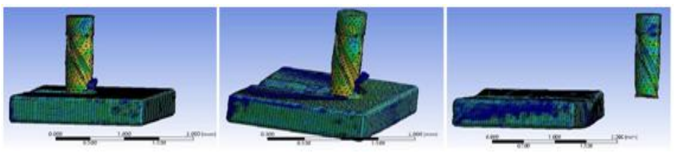
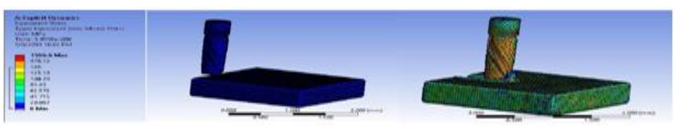
Results

(a) Entry of tool into the workpiece (b) Chip formation initiation

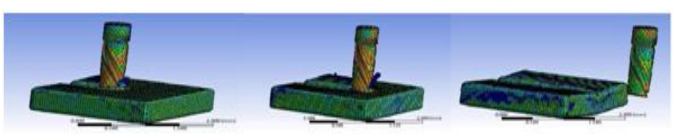


(c) Chip flow (d) Chip separation (e) Exit of tool from workpiece

Figure 5.7: Simulation of small burr formation using tool with rake angle 3º and relief angle 8º



(a) Entry of tool into the workpiece (b) Chip formation initiation



(c) Chip flow (d) Chip separation (e) Exit of tool from workpiece

Figure 5.8: Simulation of small burr formation using tool with rake angle 5º and relief angle 6º

Conclusions and Future Directions

This chapter concludes the technical sum-up of the thesis work on three-dimensional geometric modeling and analysis of small end milling cutters and simulation of small burrs formed during small milling of Al6061-T6 alloy by using a tungsten carbide two flute small end mill cutter. This is followed by directions for future work.

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