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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.

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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 strongly influenced by the highest possible quality and productivity achieved. This can be achieved only when the parts and/or products have excellent surface finish. One of the important causes of poor surface finish is the formation of burrs along the machined edges / boundaries. The impact of burr formation on the surface finish of smallstructures is much more significant than in case of macrostructures because of comparable sizes of burrs and the parts formed during small machining. Deburring in this case is expensive, and sometimes impossible, and, hence, the only solution is to minimise the formation of burrs. To realize any surface accurately using conventional subtractive machining process, two most important factors to be properly controlled are: geometry of the cutting tool and the kinematic structure of the machine tool. The cutting tool geometry along with the relative motion between the cutting tool and the work piece generates the profile of the cut. Even the shapes not possible to manufacture earlier are achievable due to increased control of machine tools by CNC controllers. Optimising the cutting tool geometry or the machining parameters or both, can help in the control of burr formation in small machining.

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 [1]. In today’s competitive world, every industry is dependent on the adequate functionality of its small components. Automobile and aerospace industries need extremely good quality machined components due to greater complexity of the workpiece, tighter tolerances, miniaturization and use of new composite materials. In case of biomedical devices, there are stringent requirements for form and finish of the product like metallic optics and cochlear implants. Good surface finish of small-components is needed for proper functioning of the products, and for proper mating of small-parts [2].

Problem Definition:

This work is an attempt to optimize small milling tool parameters for minimization[3] of small burrs formed during small machining. The objectives of this work are stated as follows:

1. To develop three-dimensional solid models of two flute and four flute flat-end small milling cutters.

2. To perform the static finite element analysis of the tools during small milling.

3. To perform the finite element detailed analysis of the tool and work piece combination during small milling

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

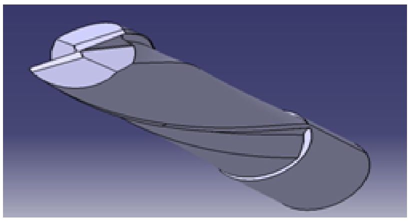

Figure 4.2: CATIA model of two flute small end mill

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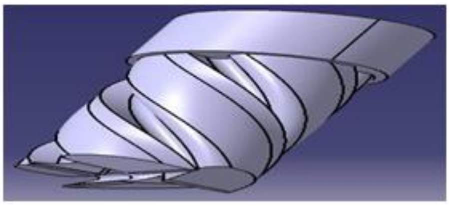


Figure 4.3: CATIA model of four flute small end mill

Analysis and Simulation:

Once a three dimensional [4]CAD model of small end mill cutter is developed, a no. of downstream applications can be performed, one of which is detailed finite element 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.

Table 5.1: Alloy composition of Al6061-T6

Elements	Minimum (% by weight)	Maximum (% by weight)
Silicon	0.4	0.8
Iron	0	0.7
Copper	0.15	0.4
Manganese	0	0.15
Magnesium	0.8	1.2
Chromium	0.04	0.35
Zinc	0	0.25
Titanium	0	0.15
Others	0.05	0.15
Aluminium	95.85	98.56

Table 5.2: Properties of Tungsten Carbide and Al6061-T6:

Properties	Tungsten carbide (Tool)	Al6061-T6 (Work piece)	Units
Density	15.63	2.703	g/cm^3
Poisson's Ratio	0.2	-	-
Young's Modulus of Elasticity	550	69	GPa
Ultimate tensile strength (UTS)	344.8	310	MPa
Tensile Yield Strength	-	276	MPa
Specific Heat	184	885	J/kgK

In research work done, it has been observed that, in case of small milling, the depth of cut and the tool diameter are the main parameters, which influence the burr height and thickness significantly. The speed and the feed rate have been seen to have small to negligible effect on the burr thickness and height. In the proposed method, different sets of machining parameters have been used for static and dynamic analysis as show in Table 5.3. These parameters have been kept constant during each analysis.

Table 5.3: Machining parameters:

Properties	Static analysis	Dynamic analysis
Cutting speed	10,000 rpm	20,000 rpm
Feed rate	150 mm/min	500mm/sec
Depth of cut	0.2 mm	0.1 mm

Five different sets of relief and rake angles each have been used in the case of two flute and four flute small end mill as input as listed in Table 5.4.

Table 5.4: Small mill cutter parameters:

Properties	Two flute flat end small mill cutter					Four flute flat end small mill cutter				
Relief angle (degrees)	0	2	3	5	5	0	2	3	5	5
Rake angle (degrees)	10	6	8	5	6	10	6	8	5	6
Cutter diameter (mm)	0.30					0.38				

Meshing:

Meshing can be done by using tetrahedral or hexahedral elements. More the no. of nodes in the element type, the greater is the accuracy of the results obtained. Tetrahedral meshing is a robust meshing routine and is easier way of meshing. However, linear tetrahedral elements perform poorly in problems with plasticity, nearly incompressible materials, and acute bending. Also, tetrahedral elements consider a lot of approximations, even more so in complicated structures.

Hexahedral elements, on the other hand, give more accurate results than tetrahedral elements, in case of complex structures. They also consider lesser amount of approximations. However, hexahedral elements face difficulties at corners of parts/elements. Also, automatic mesh generation is often not feasible for building many three dimensional hexahedral meshes. Meshing and analysis of the small milling machining operation has been carried out using ANSYS 13.0 software. The mesh generated for the end mill cutters in this work is a tetrahedral mesh, the properties of which are given in Table 5.5 and Table 5.6.

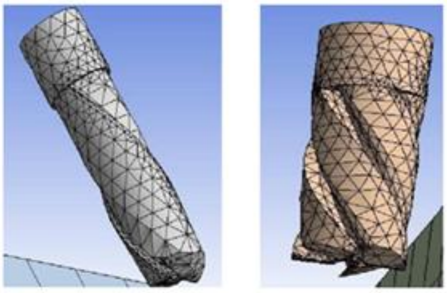


Figure 5.1: Meshing performed on (a) two flute and (b) four flute small end mill

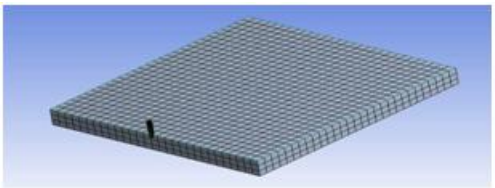


Figure 5.2: Meshing performed on the work piece

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 = 0^{o}, Relief angle = 10^{o} (b) Rake angle = -2^{o}, Relief angle = 6^{o} (c) Rake angle = 3^{o}, Relief angle =8^{o}(d) Rake angle = 5^{o}, Relief angle = 5^{o} (e) Rake angle = 5^{o}, Relief angle = 6

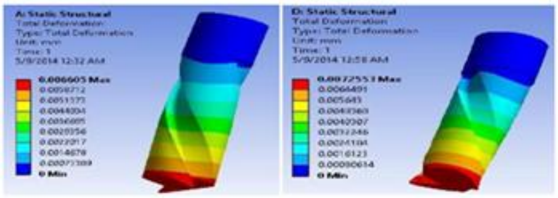
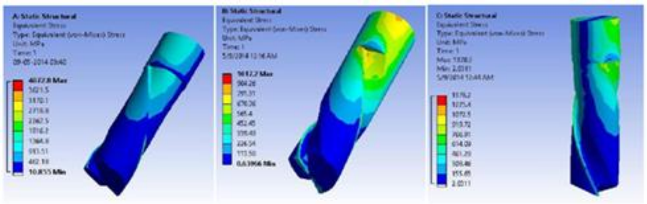


Figure 5.3: Total deformation in the case of two flute small end mills



(a) Rake angle = 0^{o}, Relief angle = 10^{o} (b) Rake angle = -2^{o}, Relief angle = 6^{o} (c) Rake angle = 3^{o}, Relief angle =8^{o} (d) Rake angle = 5^{o}, Relief angle = 5^{o} (e) Rake angle = 5^{o}, Relief angle = 6^{o}

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

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

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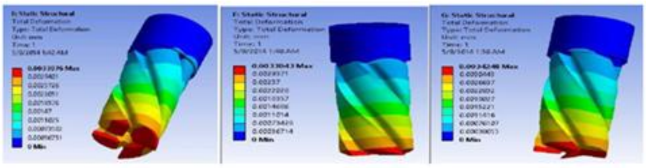
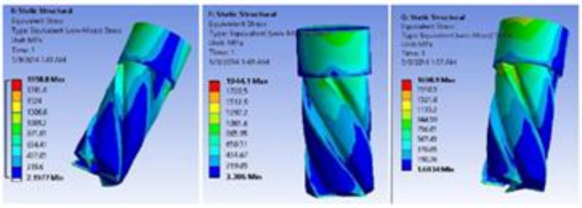


(a) Rake angle = 0º, Relief angle = 10º (b) Rake angle = -2º, Relief angle = 6º (c) Rake angle = 3º, Relief angle =8º (d) Rake angle = 5º, Relief angle = 5º

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 =

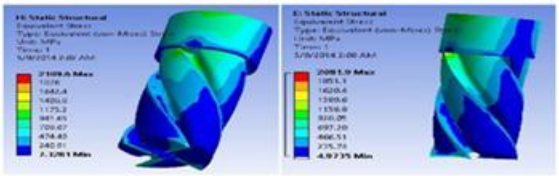


Figure 5.6: Von Mises stress in the case of four flute small end mill

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.

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

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

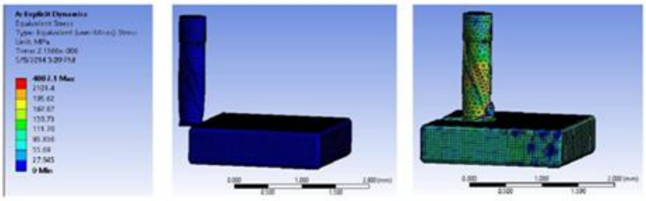
Analysis:

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 have achieved the same using ANSYS software. Two different two flute small end mills have been used for dynamic finite element analysis. ALE has been used for carrying out the analysis. Reference frame for the tool is chosen to be Langrangian and that for the workpiece is chosen to be Eulerian. In order to get required interaction between the two bodies, the required body interaction constraints among them must be defined properly.

Since the desired result is the simulation of machining operation, the contact between the tool and the work piece has to be frictional in nature. When the tool runs over the work piece, the friction generates heat energy. The chip carries the heat from the work piece and releases it in the environment. So a frictional contact is defined between the tool and the work piece. The static coefficient of friction is kept to be 0.39 and the dynamic coefficient of friction is kept to be 0.32 (Raczy et al.). The work piece is fixed from three faces. The two side faces are given zero degree of freedom as they are constrained using mechanical fixtures while machining. The lower surface is given zero degree of freedom as they are held using vacuum fixtures. The tool is provided with an angular velocity of 20,000 rpm (Campos et al. [2013]).

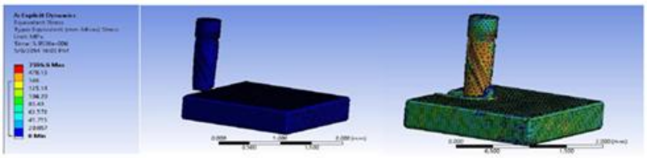
In the input variables, tool is provided with a linear velocity, which represents the feed rate of our machining operation. The feed rate in our setup is fixed to be 500 mm/sec (Campos et al. [2013]). The end time specifies the no. of iterations to be performed by the solver and informs the solver when to stop the process. Since the work piece is 20 mm in length, and the feed rate is 500 mm/sec, an end time of 0.05 seconds was chosen so that the entire tool length can be covered in the simulation. The total time taken in order to solve is 120 hours.

5.3.2 Results

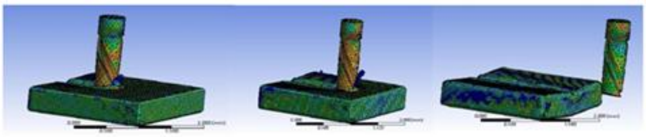


(a) Entry of tool into the workpiece
(b) Chip formation initiation

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



(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 5° and relief angle 6°

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.

Concluding Remarks:

Burr formation is a major hindrance to good surface finish in case of both macro and small milling. However, burr formation in case of small milling is of greater importance than in case of conventional milling as burrs formed in the former case are of sub-smallmeter size and deburring processes are expensive, and sometimes impossible. Hence, burr minimization is the only way of obtaining good surface finish in smallstructures. To minimize formation of burrs in case of small milling, either the cutting conditions or the tool geometry can be optimized. In this work, tool geometry optimization has been tried to be achieved by performing FE analysis on tools with different sets of rake and relief angles, for both two flute and four flute small end mills. The results of the static finite element analysis of the tungsten carbide flat end small milling tools offer the conclusion that in the given cutting conditions, the least amount of Von Mises stress generated in case of a two flute flat end small mill cutter is for a cutter having rake angle -2° and relief angles of 6° and that in the case of four flute end small mill cutter is for a cutter having rake angle 3° and relief angle 8°. FE dynamic analysis of the tool-chip interaction in the small milling process as performed and small burr formation process was simulated using ANSYS 13.0 software.

Future Scope:

The results obtained from static FE analysis of small end mills can be used in future to predict tool life and to choose the correct cutter geometry from available options for performing various small milling operations. The results obtained from dynamic analysis of small burrs formed during small-milling operation in Al6061T6 can benefit the aerospace industry, which utilises this alloy for fabrication of a large number of components.

The results obtained during the analysis may also be used for further research for burr minimization

References:

[1]Afazov, S.M., Ratchev, S.M. and Segal, J., Modelling and simulation of small-milling cutting forces, Journal of Materials Processing Technology, Vol.210, pp. 2154-2162 (2010).

[2]Alrabii SA, An experimental study of burr formation in drilling and slot-end milling operations, Journal of Engineering, 15(4) (2009) 4219- 4240.

[3]Ávila M, Gardner J, Reich-Weiser C, Tripathi S, Vijayaraghavan A, Dornfeld D. Strategies for Burr Minimization and Cleanability in Aerospace and Automotive Manufacturing. SAE Transactions Journal of Aerospace, 114 (1), pp. 1073-1082 (2006).

[4]Aziz M, Ohnishi O, Onikura H, Innovative small hole machining with minimum burr formation by the use of newly developed small compound tool, Journal of Manufacturing Processes, 14 (2012) 224–232.