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Experimental Investigation into Micro Milling of AA6063 T6 Aluminium Alloy

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Abstract

The machine components size is reduced day by day with the reduction of size of machine and also with the enhancement of the capability of various products. This trend is only going to increase in the future technological development of broad spectrum of products. This work presents an experimental study on the micro milling of aluminum alloy (AA6063 T6). The goal of this work is to study impacts of cutting forces and process parameters for fabrication (micro milling) of micro parts to reduce error and improve accuracy. The impacts of different feeds, spindle speeds, depth of cuts have been investigated experimentally. Cutting forces in two directions were also measured during the process.

Keywords: Micro milling, Computer numerical control (CNC) machine, feed, spindle speed, depth of cut, material removal rate.

1. INTRODUCTION

Reduction of size of parts is happening with every new launch of products due to their increased functionality and aesthetics. This requirement to fabricate smaller components resulted into development of new micro manufacturing techniques. Micro milling is one of the machining processes that is extensively used to machine micro-parts and micro shapes.

Air force industry was mainly responsible for the flourishing of the computer-based automatic machine tool controls known as the numerical control (NC) machines due to their complex aircraft component requirement [1]. The automation of the machining process has been made possible by the modern inventions of the computer NC machines. This also helped manufacturing industry to provide high accuracy and good surface finish to components for modern products of various applications.

Machining process becomes complicated due to size effect when size of components (workpiece) is very small [2]. The size effect causes very change in normal operational variable conduct.

Camara et al. [3] reviewed micro-milling process having special importance on the work piece and tool material properties requirements, tool signature, machining forces and conditions, accuracy and precision of the machined work piece, unevenness formation in work piece, mathematical and computational simulation, and signal processing and health monitoring of machine tools and its requirements.

Konig et al. [4] studied the micro drilling process for increasing the tool life. They observed that the proper removal of chips will result in better tool life. Jin and Altintas [5] computed the micro-milling forces using finite element simulations based on geometric conditions.

Bao and Tansel [6] developed mathematical model to calculate force for micro-milling process by taking account of chip thickness and course of tool tip.

Chae et al. [7] investigated on micro cutting operations, benefits of use of miniature parts for micro milling process. Micro-mechanical machining is well suited to support the development of micro-injection molds accurate, low cost, small batch size processes of 3D molds using ferrous alloys.

Kang et al. [8] formulated a force model to compute forces in micro milling process. They also studied its effect on tool wear and quality of generated surface. They validated their model experimentally.

Rahman et al. [9] studied micro milling of pure copper. They observed the chips formed while processing. They found that the tool life is affected by depth of cut and feed. Araujo et al. [2] investigated micro milling of an aluminium alloy on the effect of feed rate, cutting velocity and axial depth of cut. They also compared experimental and simulated forces.

Literature review presented above reveals that very few attempts appear to be performed on the micro milling of aluminum alloys. The objective of present investigation intends to study the machining (micro milling process) behavior of AA6063 T6 aluminum alloy. The present work deals with the development of the experimental setup to conduct micro milling, experimental investigations and cutting force analysis.

2. EXPERIMENTAL SETUP AND EXPERIMENTATION

In this section, details of the experimental setup, selection of process parameters and the experimental procedure have been discussed.

2.1 Experimental Setup

The experimental setup to carry out micro milling operation consisted of CNC machine, NI Elvis II, sensors (strain gauges), wheat stone bridge and other parts for satisfactorily functioning of setup. Micro-milling process involved various process parameters such as spindle speed, feed rate and depth of cut. With the use of digital balance meter, the mass of work piece was measured; cutting time was also measured for each milling operation.

Spindle speed, feed rate and depth of cut were selected as the process variables for present experimental study. The parameters were selected mainly based on literature review and

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machine limitations. The working range of the parameters was selected based on literature review and pilot experiments. It was observed that if the parameters selected have the values above the selected range then the sudden tool breakage takes place. The table 1 gives shows the process variables with their ranges and units. Tool material was high speed steel. AA6063 T6 aluminium alloy (of length 90 mm, width 20 mm and thickness 3 mm) had been used during experimentation because of its extensive use in various consumer products. As the operation was being performed at micro level due to the tool used was of very small size (0.7 mm diameter), and couldn't be fitted to chuck directly. Therefore, pin vise was used to hold the tool then pin vise (Fig. 1 and Fig. 2) was attached to the chuck. The tool used for experimentation was having diameter of 0.7 mm. The work piece with strain gauges (120 Ω) was held on small vise as shown n Fig. 3. The strain gauges were then connected to NI Elvis II via a wheatstone bridge (Fig. 4). NI Elvis transferred signals measured by strain gauges to computer in which it was recorded for analysis.

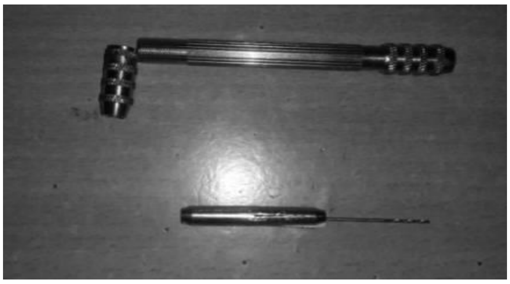

Fig. 1 Pin vise with micro-milling tool

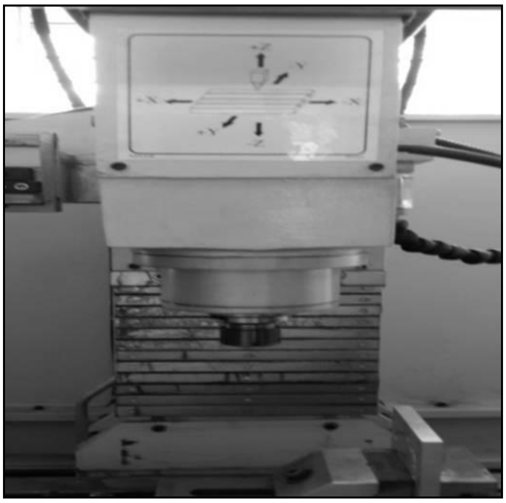

Fig. 2 Chuck of milling machine

2.2 EXPERIMENTATION

AA6063 T6 aluminium alloy had been prepared. Milling codes (GM codes) were generated. Milling operation was performed for all the combinations of the parameters. The milling time was kept constant for 3 minutes. The geometry selected for machining was square of 3 mm edge length. The machine codes were then produced for different parametric conditions (Table 1) to make a squared machined track on work-piece.

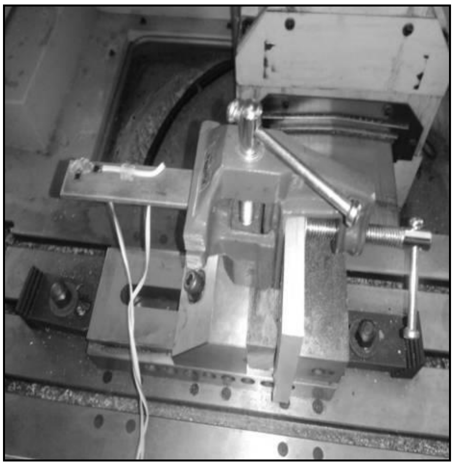

Fig. 3 Strain gauge on workpiece

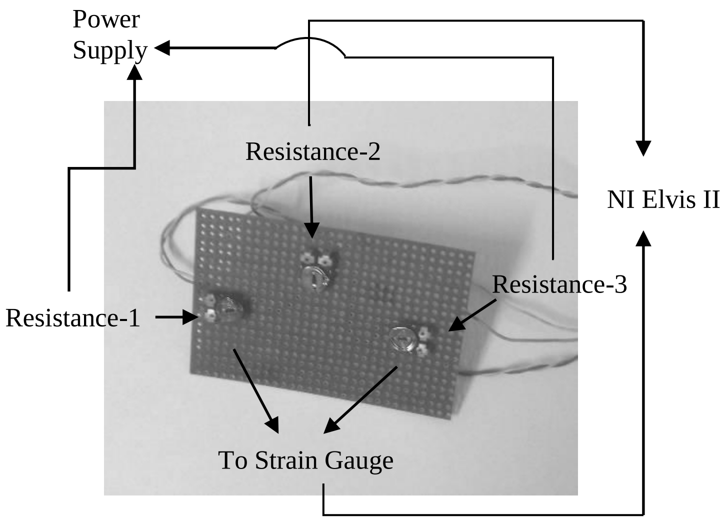

Fig. 4 Wheatstone bridge used on experimental setup

Table 1

Input parameters with range and unit

S. No.	Factor	Level-1	Level-2	Level-3	Level-4	Level-5
1	Spindle Speed (rpm)	659	1000	1500	2000	2341
2	Feed Rate (mm/min.)	0.5	1	1.5	2	2.5
3	Depth of Cut (mm)	0.05	0.1	0.15	0.2	0.25

After obtaining all the data through the experiment, calculation of MRR (Material Removal Rate) in gram/minute was performed. Material Removal Rate (MRR) is the mass of the material removed in the operation at per unit time during cutting in the operation.

MRR= M/T (gram/min) (1)

Here,

M=mass of material removed in gram

T=cutting time in minute

High precision digital balance meter (least count 0.0001 gram) was used for measuring the mass of work piece before as well as after experiments.

Strain gauges in two perpendicular directions were attached to wok piece. The strain gauges were connected to the NI Elvis II using wheatstone bridge to provide strain signals. The NI Elvis II transmitted signals from strain gauges to computer. Sampling rate for the signals from NI Elvis II, were 3000 Hz in the selected set of experiments. This system was then calibrated by applying different weights (from 5 grams to 250 grams) to the workpiece in separate X & Y directions (against the gravity). Experiments were then carried out to obtain results. Experimental investigation has been performed on machining process. Cutting forces was measured using strain gauges while performing operation on the work-piece.

3. RESULTS AND DISCUSSION

3.1 Impact of process parameters on material removal rate (MRR)

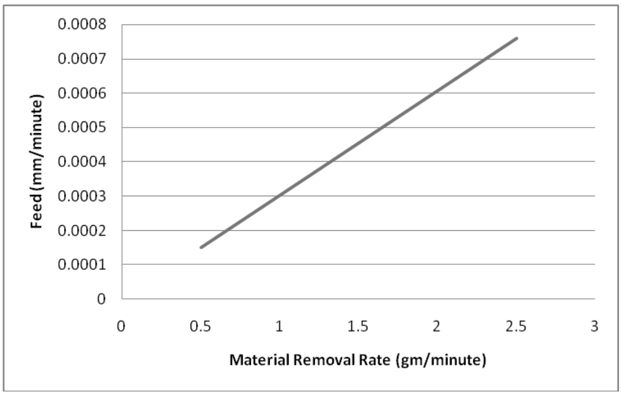

Fig. 5 Variation of material removal rate with respect to feed

As observed from the experimentation (micro milling) performed on AA6063 (aluminium alloy), fig. 5 shows the variation in the value of MRR with variation in feed. The next fig. 6 shows the variation of the value of MRR with the variation of depth of cut (DoC). The main contributor of MRR was depth of cut and feed. Spindle speed was found to be an insignificant parameter in our range of experiments. The highest value of parameters results for maximum MRR. The following equation obtained as results of the findings of experimental study.

MRR α Feed×DoC (2)

Or, MRR = 0.00202 Feed×DoC (3)

The proportionality constant found in equation 2, is 0.00202.

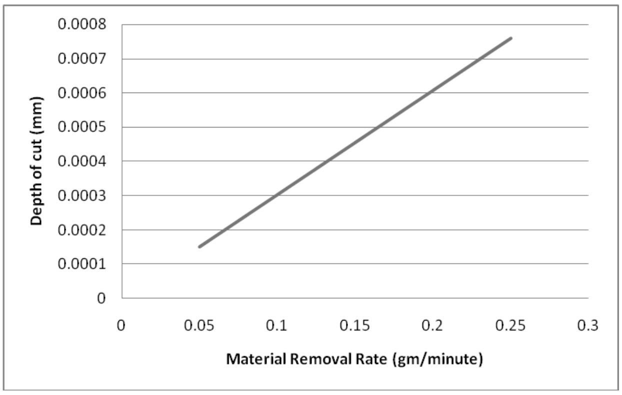

Fig. 6 Variation of material removal rate with respect to depth of cut

3.2 Cutting force analysis

Cutting forces in micro milling operation has been divided as static and dynamic parts. The dynamic part is an instantaneous force at any time during the machining. The static part is average of dynamic cutting force. Milling operation is an intermittent cutting operation in which intermittently cutting takes place by tool of work-piece. After cutting there is a time period in which no cutting takes place. This zone is resulted with no cutting force. These findings are similar to those obtained by Rahman et al. [9] for their micro milling of copper. The maximum force obtained by Rahman et al. [9] was 0.41N and 0.82N in X and Y direction respectively at cutting speed of 75m/min (8000 to 29000 rpm), feed of 350m/min and depth of cut of 0.25mm. In this work the maximum force obtained was 0.0225N and 0.0403N in X and Y direction respectively at rpm of 1500 rpm, feed of 1.5mm/min and depth of cut of 0.15mm. The values of forces obtained in this work were less in comparison to Rahman et al. [9]. It may be due to parametric conditions during experimentation. Other than this, it was also found that forces at zone in which no cutting takes place was synchronised with the spindle speed and feed. In the initial 90° motion of the spindle the force is increasing and in the later 90° motion of cutter force reduces to the lowest value. This zone is followed by cutting period in which cutting forces are observed. In fig. 7 and fig. 8 cutting forces in X and Y directions have been shown.

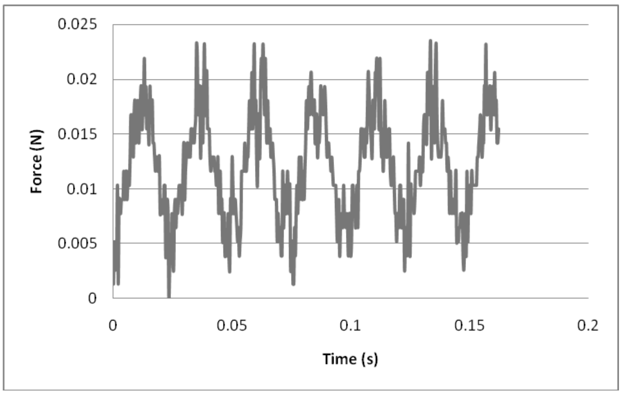

Fig. 7 Cutting force in X-direction (i.e. direction of tool motion) at spindle speed 1500, feed 1.5 mm and depth of cut 0.15 mm

The cutting force in the direction (Y- direction) perpendicular to feed is twice the cutting force in the feed direction. It can be observed that the cutting force pattern is similar to conventional milling operation.

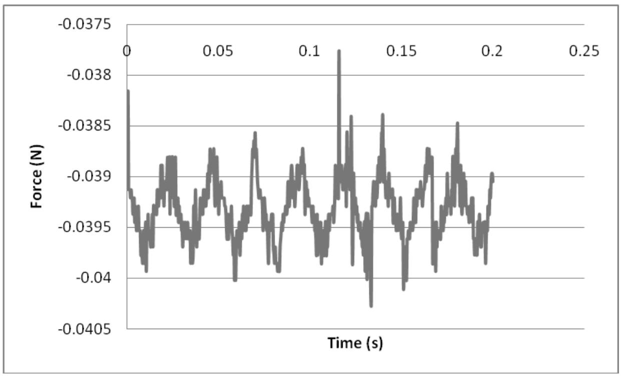

Fig. 8 Cutting force in Y-direction (i.e. perpendicular to the direction of tool motion) at spindle speed 1500, feed 1.5 mm and depth of cut 0.15 mm

4 CONCLUSIONS

In this study, the micro milling of AA6063 T6 aluminium alloy using a 0.7 mm diameter milling cutter at different parametric conditions is studied. An enquiry is also carried out for cutting forces during the operation. The values of forces have been found significantly lower than previous researcher [9]. It has been found that if the parameters selected have the values above the described range then the sudden tool breakage takes place. For stable cutting operation the given range can be successfully utilized. Maximum Cutting force in X-direction (i.e. direction of tool motion) and Maximum Cutting force in Y-direction (i.e. perpendicular to the direction of tool motion) at spindle speed 1500, feed 1.5 mm and depth of cut 0.15 mm were found 0.0235 N and 0.0403 N respectively. Micro-milling operation is an intermittent cutting operation similar to milling operation, in which intermittently cutting takes place by tool of work-piece. After cutting there is a time period in which no cutting takes place. It was found that the forces at zone in which no cutting takes place was synchronised with the spindle speed and feed. In the initial 90̊ motion of the spindle the force is increasing and in the later 90̊ motion of cutter force reduces to the lowest value.

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