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Ultrasonic Vibration Assisted Slot Milling of AA1050

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Abstract

The conventional milling of chemically reactive, soft and ductile materials like aluminium encounters several challenges like poor quality of surface finish and severe burr formation on machined part due to built up edge (BUE) formation on cutting tool. In this study, full slot milling of AA1050 aluminium alloy is carried out with ultrasonic vibration assistance to reduce the extent of problems. The characteristic study of the finished surface is done by measuring 2D and 3D roughness profiles and imaging the surface irregularities under scanning electron microscope and stereomicroscope. The cutting tools employed for various conditions are also inspected in detail to identify any built-up edge formation. The ultrasonic vibration assisted milling (UVAM) is found to produce better results over conventional milling (CM) with significant improvements in terms of surface roughness values, surface uniformity, severity in burr formation and BUE formations.

Keywords: Ultrasonic Vibration Assisted Milling, Conventional Milling, Burr, Surface roughness, BUE

1. INTRODUCTION

The aluminium and aluminium alloys have gained wide spread acceptance in industry due to their superior properties such as high strength to weight ratio, high toughness, good electrical and thermal conductivity along with excellent heat treatability and solid solution formation capabilities. These have resulted in an increase in their applications and hence a high demand particularly in aerospace industry followed by automotive and construction industries.

The conventional milling (CM) of aluminium and its alloys have always been difficult because of their inherent material characteristics leading to Built-Up Edge (BUE) formation, Built-up Layer (BUL) formation, burr formation and poor surface finish on the machined part. The BUE has been found to arise from the accumulation of a layer of work material near to the cutting edge of the tool thereby affecting the nature of tool-work interaction. The quality of the machined surface is also usually found to be lower in cases accompanied by BUE formation. The detrimental factor in aluminium machining is the aluminium phase present in these alloys. The higher position of aluminium in reactivity series compared to various other base metals causes aluminium to react with a wide range of tool materials and even protective coatings provided on cutting tools. This also leads to the sticking of aluminium phase to the tool material and thereby also the machined workpiece surface [1-6].

Several methods have been developed over years to ease out these problems in aluminium machining which include the development of diamond tools and suitable lubrication techniques. The high chemical inertness of diamond prevents its interaction with aluminium to a great extent leading to arrest of material adherence onto the tool surface and hence gives good surface finishes with the limiting factor being the cost associated with these tools [5, 6]. The lubrication techniques like those employing Minimum Quantity Lubrication (MQL) are found to lower cutting forces and thereby improve surface finish of the machined surface [7-9]. With the interest now shifting to dry machining due to environmental concerns, the improvements in lubrication does not prove to be an acceptable solution. The ultrasonic vibration assisted milling (UVAM) is an advanced milling technique in which ultrasonic vibrations are superimposed on conventional milling operation leading to vibration of either tool or the workpiece at very high frequencies and low amplitudes. The process has gained attention among researchers due to the advantages offered such as low value of cutting forces and better surface finishes obtained by overriding the conventional metal cutting kinematics significantly [10-12].

Any technique which can improve the machinability of commercially pure aluminium can be thought off to improve the machinability of aluminium alloys in general. With this view, this study deals with both CM and UVAM of the aluminium alloy AA1050. This particular alloy has near pure aluminium composition with no major alloying element present and hence is highly sticky and extremely soft in nature. Further in the study, both the processes have been compared through characterisation of the machined surfaces generated and the tools used.

2. EXPERIMENTAL DETAILS

The experimentation was carried-out by milling full slots of 5 mm width and 30 mm length on a highly sticky aluminium alloy AA1050 using a JYOTI KMILL8 HSM-make vertical machining centre. The workpiece was a rectangular bar of size 75 x 30 x 12 mm. The end mill cutters used were 5 mm in diameter and made of high speed steel. An ultrasonic vibration imparting attachment was developed that used an ultrasonic transducer to impart vibrations of amplitude 6 µm with 20 kHz frequency onto a table attached to it and was driven by an ultrasonic generator with a capacity of 3 kW. The schematic diagram of the ultrasonic unit used for the experiment is shown in Fig.1. The aluminium workpiece was clamped over the ultrasonic table and vibrations were imparted to the workpiece along the feed direction of the cutting tool. Two different combinations of cutting speeds and feed rates were

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employed for milling and each one was carried out with and without ultrasonic vibrations applied to conventional milling process. Same depth of cut was used for all slots and was set to be 0.5 mm. Separate HSS (high speed steel) end mill cutters were employed for each of the combinations. The parameter combinations used for machining are listed Table.1.

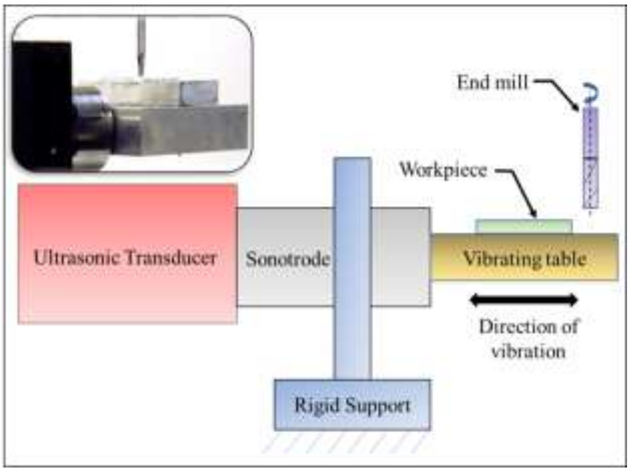

Fig.1. Schematic and pictorial (inset) diagram of ultrasonic setup

Table 1. Experimental conditions

Cond. code	Cutting Speed (RPM)	Feed rate (mm/min)	Vibration amplitude (μm)
C1	5000	50	6
C2	5000	50	0
C3	10000	100	6
C4	10000	100	0

The ultrasonic vibrations were switched off while machining slot corresponding to condition C1 after progress of cut for initial 15 mm slot length to study the transition of machined surface from conventional to ultrasonic regime.

The machined surfaces and cutting tools for vibration assisted and conventional machining conditions were characterised based on SEM images taken using Inspect F50 Scanning Electron Microscope and later using high resolution images of the surface captured using Zeiss Stemi 2000-CS stereomicroscope. The 2D surface roughness measurements were taken using a Mahr-M2 Perthometer. The machined surfaces were also studied using a Nanomap 1000 WLI non-contact surface profiler. The material characterisation along the tool surface was carried out by performing EDS analyses.

3. RESULTS AND DISCUSSIONS

From Fig. 2 and Fig. 3, it is evident that the average surface roughness Ra and the average (5 point) peak-to-valley height Rz are lower for UVAM compared to CM for the slots machined. Also for the same value of uncut chip thickness, the Ra and Rz values decrease with the increase in cutting speed and feed rate. The Rz values show a highly positive trend by giving nearly fifteen percentage lower values in UVAM compared to CM. This decrease in surface roughness can be attributed to a more uniform surface generated by the UVAM compared to CM. The feed directional vibration of the workpiece leads to an ironing action of the generated surface by the cutting tool during its movement along the feed direction which thereby levels-off the surface.

As indicated by Fig.4, Fig.5, Fig.6 and Fig.7, the surface generated by UVAM has more uniformity and less redeposited material with irregularities shifting to a much more micro scale. The reduction in redeposited material may be indicative of less BUE formation on the tool and more proper shearing and chip removal in UVAM. The ultrasonic vibration ensures smooth flow of chip over the tool face and away from the machining zone, reducing the tendency of the removed material to stick onto the machined surface being generated. The periodic engagement and disengagement of cutting edge from the workpiece during progress of each individual cutting action leads to a more effective shearing of the work material rather than ploughing or rubbing of the cutter teeth over the workpiece surface. In UVAM, each cutting tooth instead of continuously shearing out a metal chip in a single movement can be now thought off to shear out a chip in a series of stepped complex movements. This is due to the continuous forward and backward movement of the workpiece that is superimposed over the usual circular cutting motion of the

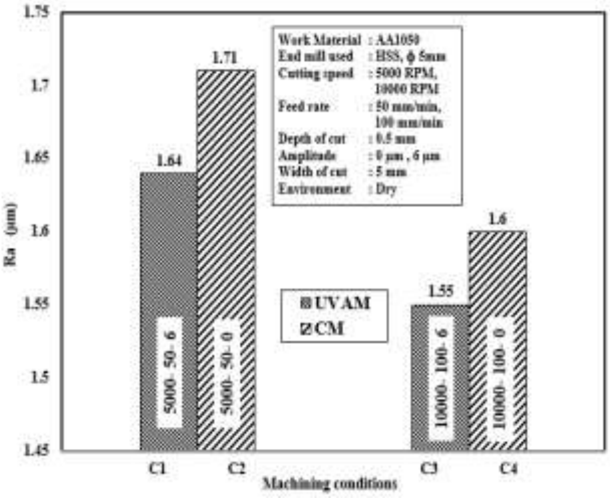

Fig.2. Ra values of machined surface roughness

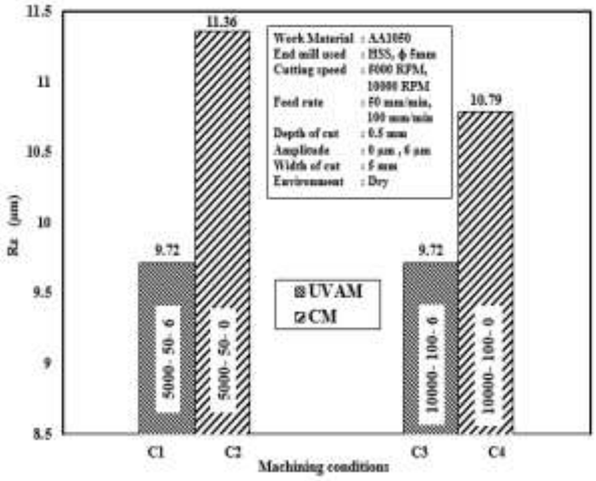

Fig.3. Rz values of machined surface roughness

cutting edge. This leads to a change in surface topography as indicated by the respective figures. The randomness of the surface in terms of occurrence of random peaks and valleys is also overcome to a large extent in UVAM compared to CM. The rubbing marks are negligible in UVAM generated surfaces which also helps in achieving better surface uniformity. The Fig. 4 and Fig. 5 also show the inner edge of the slots which is more regular and of a more proper geometry for UVAM than CM. The inner edge of slot generated in conventional milling show high irregularity which may be due to rubbing and ploughing which are predominant when uncut chip thickness in milling is lower than the critical uncut chip thickness. The better results in UVAM may be again due to the more effective shearing of the work material near to the slot edges due to the altered cutting kinematics and also due to the repeated ironing action of the tool cutting edges along the slot corners as the workpiece surface vibrates along the feed direction.

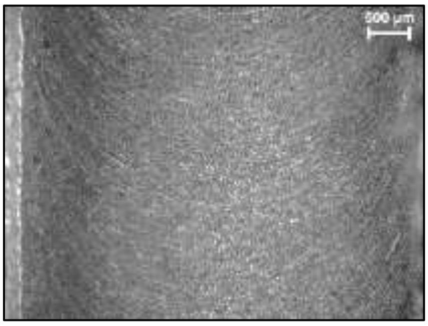

Fig.4. Stereomicroscope image of machined surface for condition C1

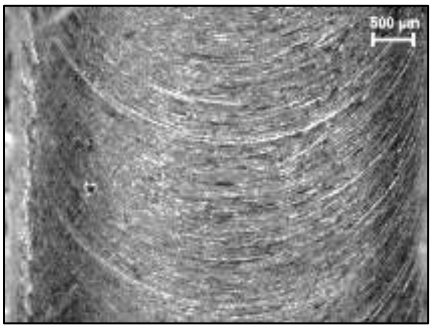

Fig.5. Stereomicroscope image of machined surface for condition C2

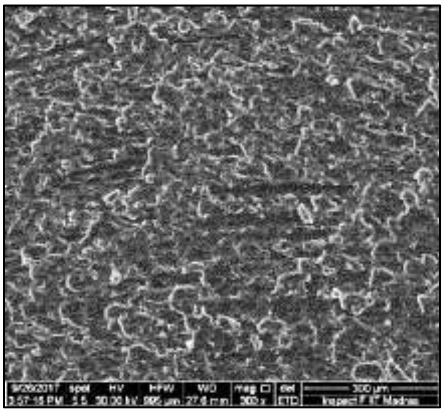

Fig.6. SEM image of surface machined with condition C1

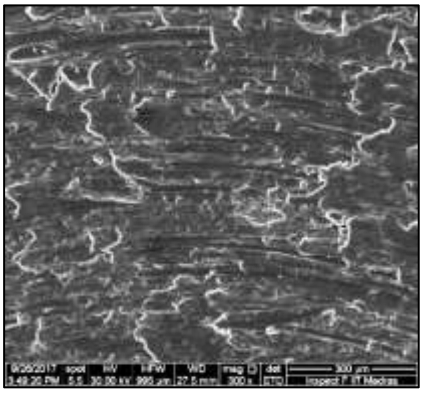

Fig.7. SEM image of surface machined with condition C2.

The Fig.8 and Fig.9 shows low magnification image of the slots corresponding to combinations C1 and C2 respectively. A fact worth noting here is that the lay marks in the feed direction in surfaces milled with vibration assistance have become more fine and uniform whereas the conventional milled surfaces show predominant lay marks throughout their length. These images also indicate the burr formation along the sides to be comparatively less for UVAM than CM, which is due to a lowered tendency for BUE formation in milling with vibration assistance.

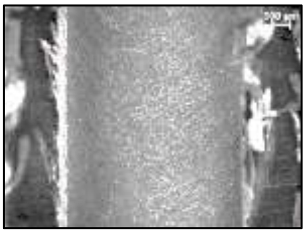

Fig.8. Machined surface corresponding to C1

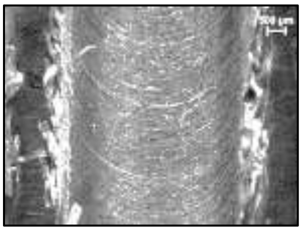

Fig.9. Machined surface corresponding to C2

The 3D profile of transition region from conventional milled surface to vibration assisted milled surface in combination C1 is shown in Fig. 10. The image shown supports the previous findings that the surface produced is drastically transformed from an irregular surface with feed marks and also with random peaks and valleys in CM to a more uniform surface with very fine feed marks and lesser material redeposition in UVAM.

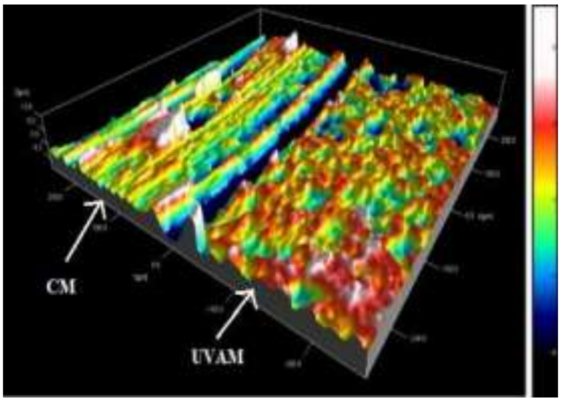

Fig.10. 3D profile of the surface showing transition from UVAM to CM

The results of the tool study reveals high BUE formation on the cutting edges and rake surfaces of the end mill cutter used in CM as shown in Fig.11. The cutter used for UVAM as shown in Fig.12 has almost no BUE formation and is in a perfect condition for further machining. This is attributed to the repeated disengagement of cutting edge from the workpiece leading to frequent breakage and prevention chip-tool bond formation along the contact length during cutting. The EDS results, shown in Fig.13, performed on the tool used for CM confirms that the built-up material is aluminium and also indicates aluminium to be the major constituent in the alloy. This agrees with the claims about pure aluminium- to be the major contributor in the BUE formation while machining aluminium alloys.

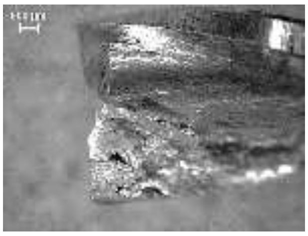

Fig.11. Tool cutting edge in CM

Fig.12. Tool cutting edge in UVAM

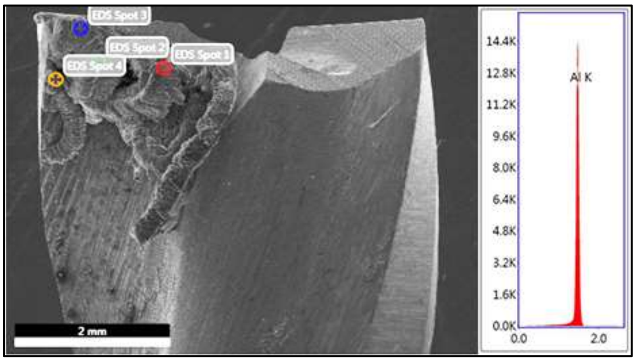

Fig.13. EDS on built up material on tool cutting edge in CM.

4. CONCLUSION

The conventional and ultrasonic vibration assisted milling of a highly sticky aluminium alloy were carried out in this study. The ultrasonic vibration assisted milling was found to produce a better quality surface having average peak to valley heights nearly 15 percent lower than conventional milling in the current working regime. The superimposition of ultrasonic vibrations on the kinematics of the tool-workpiece engagement effectively arrested the built-up edge formation on the tool surface. The machined surfaces thereby generated were much more uniform with very fine feed marks. Reduced burr formation and very less material adherence on tool tip points to a much improved shearing of the work material and smoother flow of chips on rake surface.

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