Defence Science Journal, Vol. 70, No. 3, May 2020, pp. 299-305, DOI : 10.14429/dsj.70.14831

Effect of Coating and Polishing of Cutting Tool on Machined Surface Quality in Dry Machining of Aluminium Alloy

Atul Dev[!,#,*], Smriti Tandon[#], Pankaj Kumar[$], and Anup Dutt[!]

[!]*DRDO-Defence Electronics Applications Laboratory, Dehradun - 248 001, India*
[#]*Department of Management Studies, Graphic Era (Deemed to be University), Dehradun - 248 001, India*
[$]*Amity School of Engineering and Technology, Amity University, Kolkata - 700 135, India*
[*]*E-mail: atuldevji@yahoo.co.uk*

ABSTRACT

Surface quality is one of the major concerns in any machining process. To achieve the higher surface finish, mostly concentrated on machining parameter optimisation. This study has been carried out to study the effect of coating and polishing of flute surface of the solid carbide (WC-Co) endmill cutters on machined surface quality obtained during dry machining of Aluminium alloy 24345WP. Experiments were conducted on Aluminum workpieces with Ø6 mm 2 flute end- mill cutter with and without coating/polishing and their effect on surface quality studied for linear as well as areal surface roughness parameters using white light interferometery. The study concludes that polished flute tool, despite their non-sharp cutting edges, gives considerably better surface finish due to its lowering of chip tool friction. This was also supported by the results obtained from scanning electron microscopy of the cutting tool edge as well as optical microscopy of the obtained machined surface.

Keywords: Surface roughness; Dry milling; Carbide endmill cutter; Surface topography; Measurement

1. INTRODUCTION

A manufacturing process is responsible for the type of surface that is developed on an engineered component and the quality of the surface dictates the physical appearance as well as the functional performance of the same. Machining is the most widely used method employed to produce these components. Machining operations carried in the absence of cutting fluid i.e. dry machining is safer for the machinist as well as the environment and also contributes to the reduction in overall manufacturing costs. Dry machining also leads to reduction of the use of cutting oils, associated energy consumption and industrial waste[1]. These emerging trends in dry machining have attributed to intricacies in machining aluminium and its alloys which is due to its chemical affinity to different coating materials and low melting point. The absence of coolant increases the tool-chip interface temperature and results in the formation of a built-up edge on the tool which degrades the quality of the produced workpiece surface[2,3]. Many researchers have been involved in finding out the most compatible cutting tool coatings for machining aluminium and its alloys[4].

In any machining process, most of the times surface roughness is a crucial parameter. Apart from dimensional integrity, better surface finish ensures durability, better stress bearing capability and corrosion resistance of a machined surface. The end-milling of aluminum structures for defence and aerospace industry also requires maintaining good surface finish to ensure durability of machined components[5]. Various factors like machine-tool rigidity, workpiece material, tool material, tool geometry, use of coolant, machining parameters like speed, feed and depth of cut, etc. play an important role in determining the surface quality of a machined surface. Much work has been carried out for machining parameter optimisation to get the desired surface finish. However, very less work has been carried out on the effect of tool coating/ polishing on the surface quality of the machined surface. Never the less it's a general understanding that a sharper tool gives a better surface finish. This study aims to find out the effect of coating and polishing of cutting tool on the surface quality of a machined surface.

Various commercially available tool coating options and processing technologies promise to offer solutions for enhancing the tool life as well as reducing friction, resulting in the better surface finish during dry machining of aluminium[6]. Some of these choices have been investigated earlier[4]. In the present study dry machining of Wrought Aluminium alloy 24345 WP which is widely used in aerospace and defence applications is taken for investigation for achieving minimum surface roughness using uncoated, coated and polished flute solid carbide endmill cutters.

Traditionally roughness average (Ra) value has been the key parameter in quantifying the quality of the machined surface due to the ease of measurement and understanding. As the Ra of topographically very distinct surfaces, can be the same, it does not provide conclusive evidence from the functional aspects of the workpiece. But with the advancement

Received : 14 August 2019, Revised : 20 October 2019
Accepted : 30 December 2019, Online published : 27 April 2020

of non-contact measurement techniques, hardware, and computer software a number of other parameters like 3D hybrid measurement parameters of the surface can also be assessed from the functionality point of view. The aim of this investigation is to study the effect of coatings and polishing on the responses Ra, Rz, and Sdr.

It has been claimed by the cutting tool manufactures and related literature[7] that a polished flute gives better surface finish due to their lubricity and smooth surface which facilitates chips to exit more freely. However, it has not been studied systematically that how much improvement in surface quality takes place with polished flute as compared to coated or uncoated tools. This is also a well-established fact that coating improves tool life[8].

Diamond-like Carbon (DLC) coating has a low coefficient of friction with the Aluminium alloys and has got lesser adhering properties and found out to be most suitable for dry machining of Aluminium alloys due to the reduction in the formation of built-up edge (BUE). It was also deduced that the DLC coating improves the tool life as well as the surface integrity as compared to uncoated carbide tools[4]. It was established that the diamond coating gives a smoother finish in comparison to uncoated, TiN, TiC and Al_2O_3 coated carbide tools in dry machining of Aluminum and reason was attributed to the non-wetting characteristic of diamond coating which causes smooth flow of chip over the rake face without the formation of the built-up edge[9]. It was reiterated that the use of DLC coating and chemical vapour deposited (CVD) diamond coating reduces aluminium adhesion and BUE compared to uncoated WC-Co drills. The use of DLC coating over the CVD Diamond coating in the drilling of Al-Si alloys is also established with the cost advantage[10]. A study on the dry turning of AA 6063 using multilayer coated and uncoated carbide inserts found that the tool life increased 8.75 time over the later. This was also attributed to wear resistance and friction reduction and which also led to improved surface finish[11].

A detailed investigation of micro-milling of five different coatings along with uncoated endmill cutters was done and led to finding out the better surface finish with DLC and Aluminum-Titanium-Nitride (AlTiN) coating materials when machining Inconel material. The reason was attributed to their no chemical interaction, lower chip adhesion and lower friction coefficient[12]. Higher cutting edge radius is obtained with AlTiN coating may be believed to form better surface finish on harder material. On the contrary, the uncoated tools will have the lowest edge radius, but due to initial faster wear out it leads to higher cutting edge radius and hence better surface finish for some part of machining operation[12]. To reduce the formation of built up edge in dry machining of aluminium alloys, polished tool surfaces have also been suggested by other researchers[13].

Most of the studies are concentrated around finding out the centre line average (Ra) values. The Aerial/3D surface parameters which are responsible for the actual in-service performance of the surfaces/components are not studied comparatively along with the Ra. Objective of this study is to investigate and verify the better coating materials or processing method on carbide end mill cutters for dry machining of Aluminum alloys so as to get the better surface finish and surface topography.

2. EXPERIMENTAL SETUP

Experiments were carried out for the milling process and the experimental setup as depicted in Fig.1, is as follows:

Workpiece material: Aluminium alloy 24345 was chosen as workpiece material as this material is frequently used for defence and aerospace applications.

Cutting tool: ϕ6 mm, 2 flutes, solid carbide end mill cutter (WC-Co) was used as a cutting tool material. Four variants of this tool were taken for this study, which is bare tool i.e. having no coating and no polish, DLC coated tool, AlTiN coating and the polished flute tool having flute Ra value of 0.04 µm. HSS tools have not been considered for this study as they are not suitable for dry machining of aluminium alloys[14].

Machine tool: Swiss make Mikron 21D machine was used for this experimental work. All the cuts have been taken with the following parameter setting:

RPM	: 2500
Depth of cut	: 0.25 mm
Feed	: 50 mm/min

These machining parameters have been selected based on our past experience on the said machine which give better surface quality on Aluminium alloy surface machined at 10 µm/tooth chip loads with the cutter under consideration.

Coolant: All the cuts have been taken under ‘dry milling’ condition i.e. without the use of any coolant.

Measurement System: Surface quality of the machined surface has been checked using 3D Optical Profiler, model Contour GT of Bruker make. The Bruker Contour GT is an advanced 3D non-contact optical metrology tool used for advanced surface characterisation. This instrument outputs a true topographical representation of a surface with 0.1 nm Z resolution and a 1 µm lateral resolution. The measurements were taken using 20 x objectives with a scan speed of 1 x.

For the measurement of Ra and Rz contact method was used in which cut off of 0.8 mm was taken on the Talysurf Surtronic, portable roughness tester.

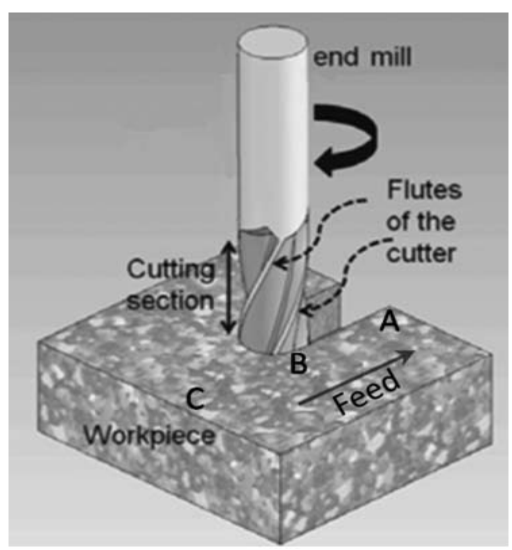


Figure 1. Experimental setup.

3. EXPERIMENTATION AND ANALYSIS OF RESULTS

Experiments were carried out on a pre-machined Aluminum alloy (24345) workpiece of size 200 mm x 25 mm x 25 mm. Cuts were taken with 4 type of 6 mm, 2 flutes solid carbide end mill cutters, which are (Fig. 2):

(i) Bare Tool i.e. having no coating and no polish
(ii) Diamond Like Coating Tool (DLC)
(iii) Aluminum-Titanium-Nitride (AlTiN) Coating
(iv) Polished Tool having Ra of the order of 0.04 µm

Three cut were taken with each type of tool i.e. total 12 cut were taken (Fig. 3). To study the surface quality of machined surface generated by each type of tool, three surface parameters were chosen Ra, Rz, and Sdr. Sdr is a 3D hybrid Parameter, which may be defined as the ratio of the developed surface (after machining in our case) with respect to the theoretically flat surface. Sdr is expressed in terms of percentage. This means a completely flat surface will have 0% Sdr. Higher the Sdr more is the area of a generated surface. A brief description of these parameters is as follows

Figure 2. Solid carbide Endmill cutters.

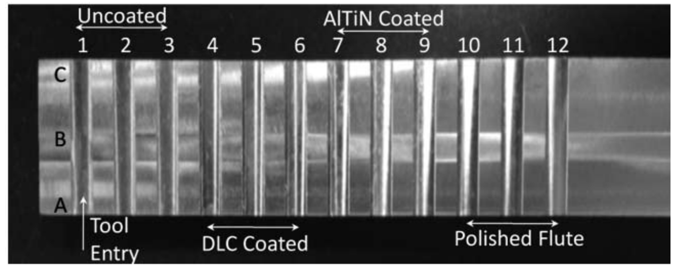


Figure 3. Aluminium alloy 24345 machined block.

(a) *Roughness Average* (Ra): It is defined as the arithmetic average value of the profile departure from the mean line, within a sampling length.
(b) *Rz:* Rz parameter is the mean of the peak to valley height of the profile taken from each sample length i.e. mean of 5 consecutive Rt values, over entire assessment length.
(c) *Sdr:* Sdr is a 3D hybrid Parameter, which may be defined as the ratio of the developed surface (after machining in our case) with respect to the theoretically flat surface. Sdr is expressed in terms of percentage. This means a completely flat surface will have 0% Sdr. Higher the Sdr more is the area of a generated surface.

Measurements of these parameters were taken at the center of each slot at three places i.e. the start, middle, and end of the slot. Results are as given in Table 1. The outputs of the Table 2. are taken from Table 1. as average of averages of the values in the different columns.

The Ra values for the polished flute tool and the uncoated tool were measured as the lowest i.e. ~ 0.280 µm followed by DLC and AlTiN coated tool. This is an improvement of

Table 1. Surface roughness Measurement Data.

Tool Type		Ra	Rz	Sdr		Ra	Rz	Sdr		Ra	Rz	Sdr
	1A	0.270	1.740	8.700	2A	0.280	1.860	6.746	3A	0.300	1.890	7.563
Uncoated	1B	0.290	1.830	8.854	2B	0.290	1.960	8.702	3B	0.280	1.890	7.253
	1C	0.270	1.920	7.527	2C	0.280	1.750	9.649	3C	0.290	1.890	7.808
		0.277	1.830	8.360		0.283	1.857	8.366		0.290	1.890	7.541
	4A	0.310	2.410	11.556	5A	0.350	2.760	16.800	6A	0.420	2.750	21.240
DLC	4B	0.310	2.050	10.456	5B	0.380	2.710	13.758	6B	0.390	2.840	20.469
	4C	0.280	2.370	9.256	5C	0.360	2.490	12.098	6C	0.440	3.470	18.083
		0.300	2.277	10.423		0.363	2.653	14.219		0.417	3.020	19.931
	7A	0.450	2.900	24.415	8A	0.420	3.010	24.243	9A	0.410	2.670	34.355
AlTiN	7B	0.410	2.730	18.216	8B	0.460	3.040	34.666	9B	0.400	2.580	32.554
	7C	0.420	2.830	15.336	8C	0.430	2.810	26.814	9C	0.420	2.900	16.205
		0.427	2.820	19.322		0.437	2.953	28.574		0.410	2.717	27.705
	10A	0.320	1.980	11.264	11A	0.290	1.840	7.116	12A	0.220	1.290	13.067
Polished	10B	0.350	2.040	15.087	11B	0.280	1.640	10.620	12B	0.240	1.510	16.569
	10C	0.320	2.020	22.926	11C	0.250	1.730	11.266	12C	0.250	1.840	17.532
		0.330	2.013	16.426		0.273	1.737	9.667		0.237	1.547	15.723

Table 2. Consolidated and Averaged Measurement Data

	Ra(μm)	Rz(μm)	Sdr(%)
Uncoated	0.283	1.859	8.089
DLC	0.360	2.650	14.857
AlTiN	0.424	2.830	25.200
Polished Flute	0.280	1.766	13.939

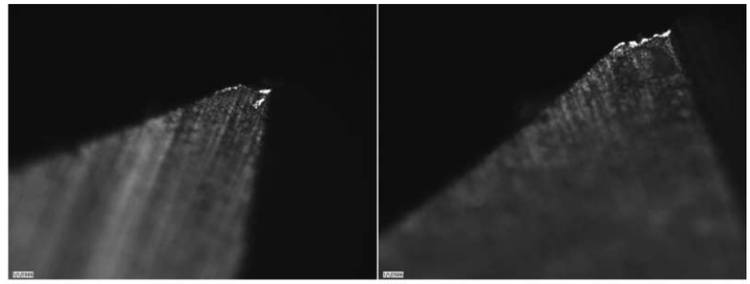
nearly 51 % over AlTiN and nearly 28 % over DLC coated tool. Rz value for the polished flute tool came out to be lowest i.e. 1.766 μm followed closely by the uncoated tool. Interestingly the Rz value of machined surface with the DLC coated tool was measured more than 50 % of the uncoated tool and AlTiN coated tool gave Rz more than ~ 60 % from the uncoated tool.

The Sdr of the machined surface obtained with the uncoated tool came out to be 72 % lesser than polished and DLC coated tool with the value of just ~8 %. This is happening because of the sharp cutting edge of the uncoated tool. Though the life of coated tool may be more, yet as far as the surface quality of the machined surface is concerned, an uncoated tool performed better under the given conditions than coated tools because of its sharper cutting edges. This thing can be further understood through the study of the surface topography of the machined surfaces as shown in Fig. 10.

The magnified images of cutting tools after machining, taken at 500x are as shown in Figs. 4 and 5. It can be clearly observed that the coated tools are prone to chip adhesion and BUE which is responsible for poorer surface quality as compared to an uncoated and polished tool. BUE formation, which occurs when the chip sticks to the cutting tool edge and has a deteriorating effect on the obtained surface finish[15]. This is further supported and can also be seen clearly in Scanning Electron Microscope (SEM) images of rake face of cutting tools i.e. chip flow side in Fig. 6. It can be clearly seen from the SEM images that coated tools are prone to buildup edge formation whereas the uncoated and polished are almost free from BUE under test conditions.

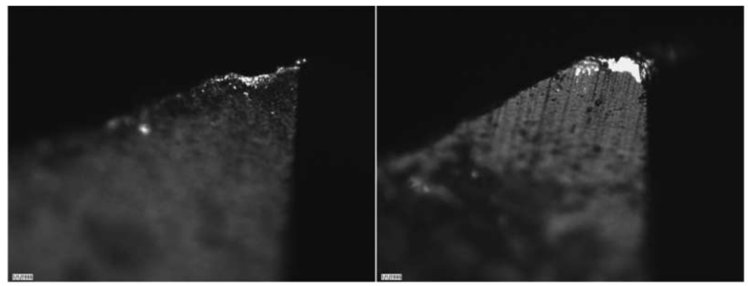
Figures 7, 8 and 9 give the graphical comparison of the surface roughness parameters Ra, Rz and Sdr obtained under the given test conditions. Figure 10 gives the magnified topographic images of the aluminium alloy surface machined at 10 μm/tooth and depth of cut 0.25 mm with various coatings and polished solid carbide tools. It is clear from the microscopic images that there is significant adherence of chips on the DLC surface and there is smearing on the aluminium alloy surface produced with AlTiN coated tool. The surfaces with the uncoated tool as well as the polished flute show little or negligible adhesion and smearing hence produce a better surface quality[12].

Chips which get adhered on the cutting edge of the tool result in altered friction conditions involving the tool and workpiece. These chips get stuck and even smudge over the workpiece surface due to the effect of temperature that crops up during the metal cutting. Chips welded on the cutting edge of the tool compress between the workpiece and tool in the



Uncoated Polished Flute

Figure 4. Uncoated and polished cutting tools edge after machining at 500X.



AlTiN Coated DLC coated

Figure 5. AlTiN and DLC coated cutting tools edge after machining at 500X.

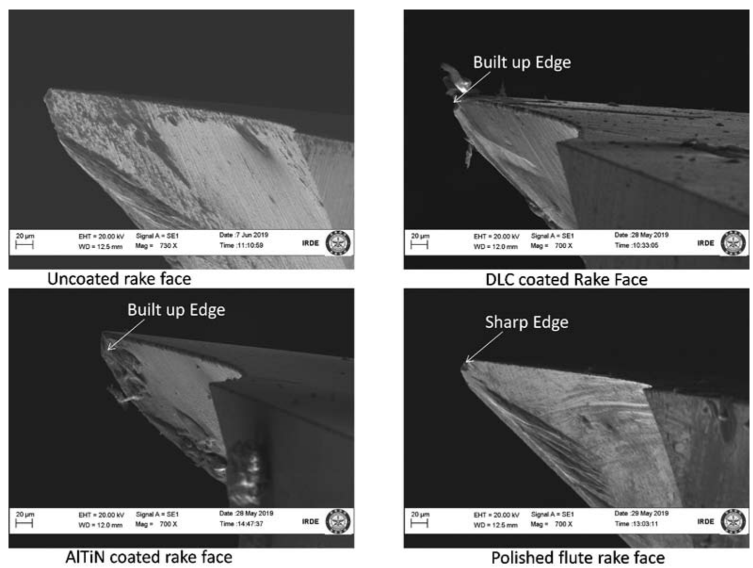


Figure 6. SEM images of cutting tools rake face after machining at 700X.

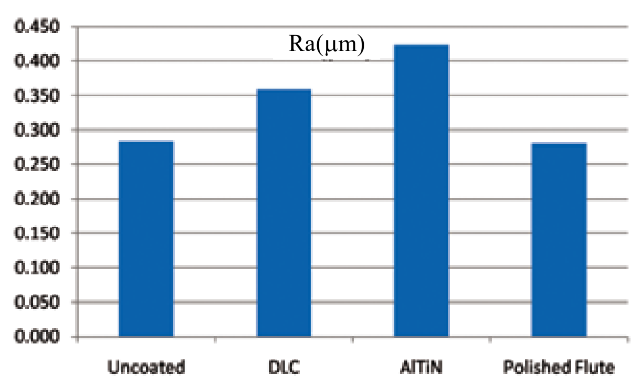


Figure 7. Bar graph of Ra.

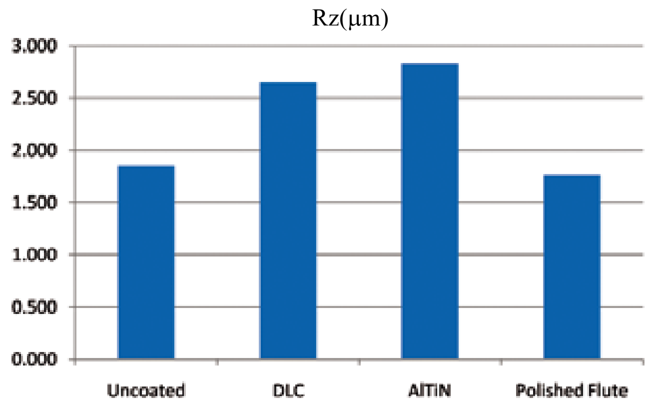


Figure 8. Bar graph of Rz.

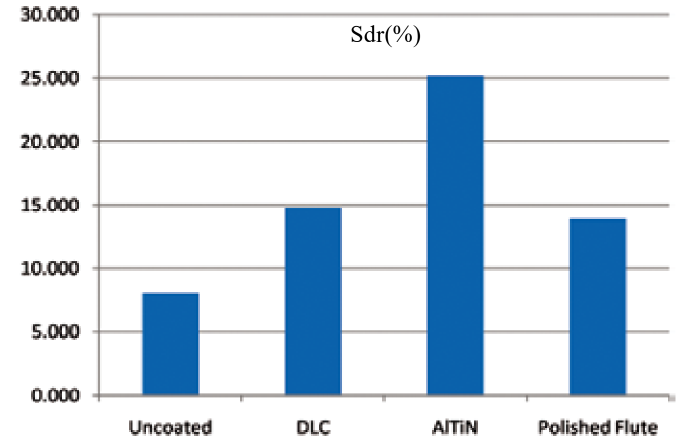


Figure 9. Bar graph of Sdr.

process. Due to this interaction of the welded chips and workpiece, some of the chip particles on the cutting edge of the tool get adhered to the workpiece surface.

Chip adhesion on machined surfaces significantly reduces the chip removal capability of the tool. As the coating increases the cutting edge radius of the tool as well as the friction between the tool-workpiece interface, it results in higher temperatures leading to BUE formation and thus poor surface finish. Further, the cutting edge of the tool losing sharpness with the effect of BUE increases the cutting tool edge radius which generates higher cutting forces during metal cutting and as a result, the generated surface quality deteriorates. The lower value of Sdr obtained with the uncoated tool in comparison to the polished flute tool is due to the fact that initially, the bare tool wears at a faster rate and the edges get rounded which generates spherical shaped cavities which have lesser surface area than the surface generated by the polished flute tool having nonrounded/beveled stabilised cutting edge.

There is no chemical interaction of the DLC coating with the material due to the presence of carbon element which helps increase the lubricity. DLC coatings in comparison to the AlTiN is much lesser in thickness (~1-2 µm) and has a lower coefficient of friction as compared to AlTiN and hence better values of surface parameters (Ra, Rz, and Sdr) in comparison to the AlTiN coated tools, are obtained. In comparison with the uncoated tool surface, DLC coated surface is considered to have better surface finish[4], still the poor performance of DLC coated tool as compared to uncoated tool, in our experiment, suggests that the reason behind the comparably poor surface finish obtained from DLC coated tool is discontinuous cutting (i.e. milling process), which may result in immediate peeling off

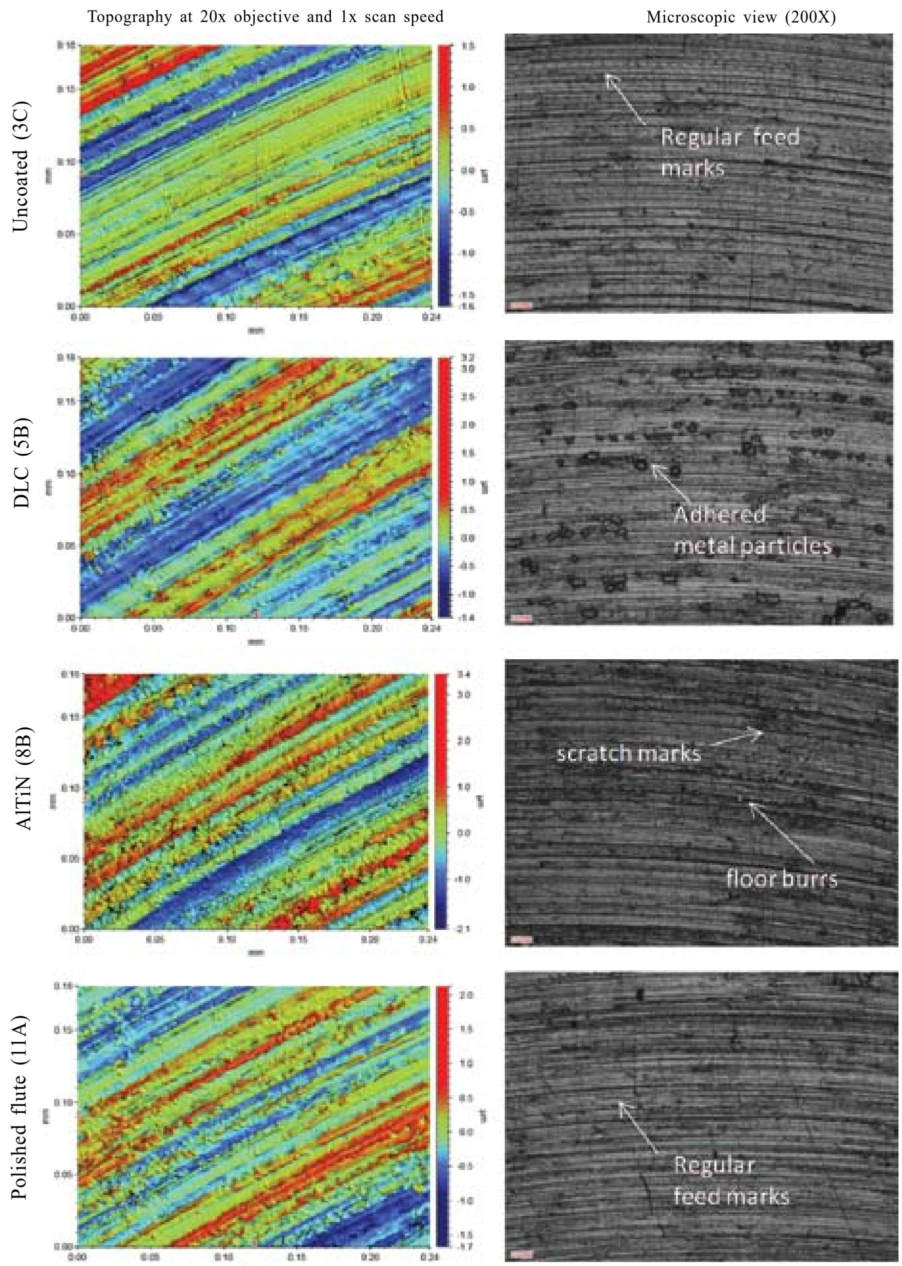


Figure 10. Topographic images of the aluminium alloy surface machined at 10 µm/ tooth and depth of cut 0.25 mm with various coatings and processed solid carbide tools.

of DLC film right from the beginning of cutting process[16]. Moreover the roughness and adhesion of DLC coating also depends on DLC coating thickness and the surface roughness of the substrate. The surface roughness of the coating as well as adhesion of the coating deteriorates with increase in coating thickness[4]. Since DLC coating thickness in our case is of the order of 1 micron Ra value, which is considered to be on the higher side, which is preferred from durability point of view, however this compromises the surface roughness of machined surface.

Higher coating thickness (~3-4 μm) is required for the desired adhesion of the AlTiN coating on the tool edge radius. The results with the AlTiN coating are the poorest for every roughness parameter under test and is due to its higher friction coefficient, higher coating thickness, and affinity to stick with aluminium alloy at higher temperatures which aid in the formation of BUE. AlTiN coating can be out rightly rejected for the Aluminium alloy end milling operation where surface finish is a critical quality parameter.

The edge of the polished flute tool becomes beveled due to the polishing operation. Despite this the cutting edge in the case of polished flute end mill cutter gets stabilised after the polishing operation, therefore no flaws or microcracks are present at the cutting edge. Hence the tendency of the deformed chips to accumulate and form BUE at these regions is reduced. The improved surface roughness of the cutting edge results in the lower friction between tool-workpiece interface which generates lesser temperature hence lessens the propensity of BUE formation as compared to the uncoated tool. This results in better values of Ra and Rz parameters in polished flute cutters.

4. CONCLUSIONS

This study convincingly concludes the following key findings:

(i) As far as surface parameters are concerned uncoated and polished flute cutters perform far better than the DLC and AlTiN coated cutters.

(ii) Among the four type of cutters studied i.e. uncoated, DLC coated, AlTiN coated and Polished flute; performance of AlTiN coated is worst from a surface geometry point of view.

(iii) Within uncoated and polished flute cutters, the performance of the uncoated tool is still better in terms of measured hybrid surface parameter i.e. Sdr.

(iv) Though it is believed that the DLC coated tools give better surface than uncoated ones, however this should not be considered as a thumb rule since the surface roughness of machined surface will also depend upon the surface roughness of DLC coated tools as well as adhesion of the coating on the tool which in turn depends upon the coating thickness and surface roughness of substrate.

Here, this may also be noted that, against popular belief, Ra alone should not be treated as the conclusive evidence for the judgment of the surface quality; Rz and Sdr give a better picture of the actual surface from the functionality point of view.

REFERENCES

1. Hiromi, Yoshimura; Yoshikazu, Toda; Moriwaki, Shibasaka; Toshimichi, Toshiro & Junya, Okida. Study on near dry cutting of aluminum alloys. *Mach. Sci. Technol.: Int. J.*, 2006, **10**:3, 289-299. doi:10.1080/10910340600902108
2. Nouari, M.; List, G.; Girot, F. & Coupard, D. Experimental analysis and optimisation of tool wear in dry machining of aluminium alloys. *Wear*, 2003 **255**, 1359–1368. doi:10.1016/S0043-1648(03)00105-4
3. Carrilero, M.S.; Sola, J.M.S.; Sanchez, J.M.; Alvarez, M.; Gonzalez, A. & Marcos, J.M. A SEM and EDS insight into the BUL and BUE differences in the turning process of AA2024 Al–Cu Alloy. *Int. J. Mach. Tools Manuf.*, 2002, **42**, 215–220. doi:10.1016/S0890-6955(01)00112-2
4. Fukui, H.; Junya, Okida; Naoya, Omori; Hideki Moriguchi, Keiichi Tsuda. Cutting performance of DLC coated tools in dry machining aluminum alloys. *Surface Coatings Technol.,* 2004, **187**, 70–76. doi:10.1016/j.surfcoat.2004.01.014
5. Kanchana, J.; Prabhuraja, V.; Prakash, R. and Radhakrishnan, P. Dynamics of high-speed machining of aerospace structures using finite- element analysis. *Def. Sci. J.*, 2002, **52**(4), 403-408.
6. Bobzin, K. High-performance coatings for cutting tools. *CIRP J. Manuf. Sci. Technol.,* 2016, **405**, 1755-5817. doi:10.1016/j.cirpj.2016.11.004
7. Richter A. Flute polishing boosts surface integrity. *Cutting Tool Engineering,* 2013. https://www.ctemag.com/news/articles/flute-polishing-boosts-surface-integrity(Accessed on 03 January 2019).
8. Jie, Gu; Gary, Barber; Simon, Tung & Ren-Jyh, Guh. Tool life and wear mechanism of uncoated and coated milling inserts. *Wear*, 1999, **225**(1), 273-284. doi:10.1016/S0043-1648(99)00074-5
9. Chattopadhyay, A.K.; Roy, P. Ghosh & Sarangi, S.K. Wettability and machinability study of pure aluminium towards uncoated and coated carbide cutting tool inserts. *Surface Coating Technol.,* 2009, **203**(8), 941–951. doi:10.1016/j.surfcoat.2008.08.047
10. Bhowmick, S.; Banerji, A. & Alpas, A.T. Tribological behavior of Al- 6.5%, - 12%, - 18.5% Si alloys during machining using CVD diamond and DLC coated tools. *Surface Coatings Technol.*, 2015, **284**, 353–364. doi:10.1016/j.surfcoat.2015.08.073
11. Das, D.K.; Mishra, P.C.; Sahoo, A.K. & Ghosh, D. Experimental investigation on cutting tool performance during turning AA 6063 using uncoated and multilayer-coated carbide inserts. *Int. J. Mach. Mach. Mater.*, 2015, **17**(3/4), 277–294. doi:10.1504/IJMMM.2015.071996
12. Ucun, Irfan; Aslantas, Kubilay; Gokce, Barıs & Bedir, Fevzi. Effect of tool coating materials on surface roughness in micromachining of Inconel 718 super alloy. *Proceedings of I Mech. E Part B: J. Eng. Manuf.*, 2014, **228**(12), 1550–1562. doi:10.1177/0954405414522217

13. List, G.; Nouari, M.; Gehin, D.; Gomez, S.; Manaud, J.P.; Le Petitcorps, Y. & Girot, F. Wear behaviour of cemented carbide tools in dry machining of aluminum alloy. *Wear*, 2005, **259**, 1177–1189. doi:10.1016/j.wear.2005.02.056
14. Nouari, M.; List, G.; Girot, F. & Gehin, D. Effect of machining parameters and coating on wear mechanisms in dry drilling of aluminium alloys. *Int. J. Mach. Tools Manuf.,* 2005, **45**, 1436–1442. doi:10.1016/j.ijmachtools.2005.01.026
15. Masounave, J.; Youssef, Y.A. & Beauchamp, Y. & Thomas, M. An experimental design for surface roughness and built-up edge formation in lathe dry turning. *Int. J. Quality Sci.,* 1997, **2**, 167–180. doi:10.1108/13598539710170803
16. Folea, Milena; Roman, A. & Lupulescu, N. An overview of DLC coatings on cutting tools performance. *Academic J. Manuf. Eng.*, 2010, **8**, 30-36.

CONTRIBUTORS

Mr Atul Dev did BTech (Mechanical Engineering) from GB Pant University of Agriculture and Technology, Pantnagar, in 1991, MSc (Quality Management) from Birla Institute of Technology and Science, Pilani, in 2004. Currently he is working as Scientist ‘G’ and Group Head, Centre for Advance Mechanical Engineering (CAME) with DRDO- Defence Electronics Applications Laboratory, Dehradun. His area of specialisation includes Taguchi Optimisation Techniques and Six Sigma problem-solving techniques. He has published seven research paper in the Conferences.

In the current study, he carried out literature review, gap identification, selection of materials and tooling, carrying out experimental work and measurement planning with interpretation and analysis of results.

Dr Smriti Tandon is working as Assistant professor in Department of Management Studies at Graphic Era (Deemed to be) University, Dehradun. Her specialisation is accounting and finance. She has published several papers in journal.

In the current study, she helped in conceptualisation of the test strategy, measurement data analysis, interpretation of results.

Dr Pankaj Kumar received his MSc (Statistics) from Delhi University, Delhi in 1997 and PhD (Statistics) from H.N.B. Garhwal (central) University, in 2009. Presently, he is working as an Associate Professor in the Department of Faculty of Management Studies AMITY University, Kolkata India. He has published seven paper in journals and many more in various conferences. His research area is inventory control.

In the current study, he has helped in literature survey and also contributed in reviewing the results and review of overall content of the manuscript.

Mr Anup Dutt, obtained his MTech (Mechanical Engineering) from Indian Institute of Technology, Roorkee, in 2017. Presently working as Scientist ‘D’ at Centre for Advance Mechanical Engineering (CAME) with DRDO-Defence Electronics Applications Laboratory, Dehradun, India. He is working in the field of Precision Manufacturing. His area of interest includes conventional micromachining.

In the current study, he contributed in procurement of cutting tools, carrying out the experiments, collecting data through different measurements with interpretation and analysis of results and preparation of manuscript.