INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY
IJARIIT

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 7, Issue 6 - V7I6-1192)
Available online at: https://www.ijariit.com

High-speed machining in milling process – A review

Hemant Kumar P.
hemantkumar.18me@kct.ac.in
Kumaraguru College of Technology, Coimbatore, Tamil Nadu

Madhumitta P.
madhumitta.18me@kct.ac.in
Kumaraguru College of Technology, Coimbatore, Tamil Nadu

Sankar Vignesh M.
sankarvignesh.18me@kct.ac.in
Kumaraguru College of Technology, Coimbatore, Tamil Nadu

ABSTRACT

This article presents a review work on high-speed milling as reported in various journals and proceedings. High speed milling is an advanced metal cutting process which involves rapid speed and feed rates to improve the productivity and surface finishing quality. This technology eliminates the disadvantages of traditional machining. Wear and breakage of tools, material behaviour certain hard to machine metals, effects of various cutting parameters on surface finish and its modern technique are discussed in this paper.

Keywords: *High speed milling, wear, cutting parameters, surface finish.*

1.INTRODUCTION

High speed machining is an advanced technology in the manufacturing field with a great potential in Upcoming the days [1]. High speed machining is one which in comparison with conventional cutting enables to increase efficiency, accuracy, and quality of workpiece. The first definition of high-speed machining was proposed by Carl Saleman in 1931.They assumed that at a certain cutting speed which is 5-10 times higher than conventional machining. High speed machining is performed on material with hardness within the 45-68 HRC range using a variety of tipped or solid cutting inserts. They provided a greater result in all the metal cutting processes but specifically in milling they have higher degree of process fineness. The various aspects in high-speed milling are reported in this paper. Rafal Pasko et al [2], presented the effective way of cutting in HSM (High Speed Machining). The decrease of temperature at the cutting edge starts from the cutting speed of different materials. HSM is used often in finishing hardened steel for both feed and speed. The result shows it ensures high metal removal rate, boosts productivity, high surface finish and it eliminates the need of coolants, and it also gives numerous benefits. Adrian Teo et al [3], presented that HSM is to improve the machining by higher than the normal spindle speed coupled with high feed rate. Benefits from the application of HSM includes reducing cycle time and improving tool life via tricordial tool path and improvement in surface finish. HSM is quickly becoming an exercise in time and material waste.

2.TOOL BEHAVIOUR

Since high-speed milling involves high spindle speed and temperature generation it is important for the tool to be suitable enough to undergo such hard machining conditions. Mostly diamond, carbide, ceramic and titanium alloys are used as tools.

2.1 Polycrystalline diamond tool: John Bonney et al [4], in this paper, to analyze the behaviour of Polycrystalline diamond tool while machining the Ti–6Al–4V alloy at high-speed conditions and high supply of pressure coolant. The results show the high coolant pressure at 20.3 MPa and lower speed conditions, there is no difference in tool performance, when Machining at high-speed conditions. Flank and nose wear are the most failure modes when machining titanium, Ti–6Al–4V, alloy with PCD tool at high pressure coolant supplies.

2.2. Ceramic tool

2.2.1. Monolithic ceramic tool: Michal sajgalik et al [5], is to identify the properties of Monolithic ceramic Milling tool while Machining hard to machine material such as nickel alloy, and analyze the technical parameters such as tool wearing, surface roughness, surface quality. The result shows that by using monolithic ceramic, it reduces the production time and increases the quality of machined parts. While Machining on Ni alloy requires a higher cutting speed than conventional machining. The conventional cutting speed of monolithic ceramic Machining the hard machine material which is 5 times lower than HSM.

2.2.2. Full body ceramic end milling tool: Damir Grguras et al [6], experimented an experiment on in conel 718 to compare the suitability of full body ceramic end mill tool with full body carbide tool. The results indicated that ceramic tool had a tool life of 3.1min under dry and 3.2 in air blast conditions respectively while carbide tool had a tool life of 6 mins under lubrication of oil CLF emulsion. With the usage of MQL the wear mechanism of ceramic tools is chipping off cutting edges, making it prone to brittle fracturing. Ceramic tool has a better total material removal rate with 18.2cm^3. But it is stated that the cost of a ceramic tool is twice more than that of the other, which is a factor that needs to be considered.

2.2.3. Solid SiAlON based ceramic tool: Ali Çelik et al[7], investigated the wear behavior of new SiAlON based ceramic tools (an α/β-SiAlON and its TiN reinforced composite) for the milling operation of Inconel 718(a nickel alloy) which hard to operate due to its high hot strength and hardness, high reactivity with the tool materials and low thermal conductivity, for a period of 30 minutes at a speed of 585 m/min which is 10 times faster than the conventional machining speed for a carbide tool and concluded that above 1000 deg celsius, the inclusion of TiN particles into SiAlON increases the resistance for diffusion zones till the reaction between TiN,SiAlON and inconel grains happens. The resistance provided by TiN is greater than the SiAlON grains. Over a period, the adhesion process occurs since it operates at a very large temperature resulting in a diffusion layer formation, but it is easily removable.

2.3. Carbide tools

2.3.1. TiAlN- and TiSiN-coated carbide tools: C.Y. Wang et al [8], in this paper conducted a high-speed milling experiment on hardened steel of specification SKD11/HRC62, S136/HRC51 with two carbides coated tools TiAlN- and TiSiN to determine the wear pattern and tool life of these tools. From the result it is inferred that the mechanism of tool wear is dependent on the effects of 1. tool angle,2. tool diameter,3. tool extended length,4. cutting force and 5. vibration due to cutting. Wear patterns of tools includes 1. flank wear,2. rack face wear,3. breakage and 4. micro-chipping. Mode of breakage was influenced by coating peeling, chipping and tip breakage. In comparison of both tools, due to reduced abrasive wear the tool life of TiSiN was better than that of TiAlN. Minimal extended length of tool resulted in spiral chips, with increase in length resulted in c shaped chips and with further increase in length resulted in saw tooth shaped chips along with reduction in surface quality. Hence it is stated that an optimal extended length of tool will assists with

- Minimum cutting force.
- Small degree of tool wear
- Best machining quality

Tools with small rake angle and suitable clearance angle and large helix angle can ensure smooth cutting operation by reducing cutting force and tool wear.

2.3.2. Nano-crystalline diamond (NCD) coated carbide tool: K. Aslantas et al [9], conducted an experiment to compare the cutting performance of NCD coated tools with TiN coated,AlCrN coated and uncoated carbide tools by micro milling of Ti6Al4V alloy. From the results they concluded that at a critical feed rate Fz=0.25 micrometer, the results exhibited by all the tools were the same. Cutting forces of uncoated and NCD were larger than the TiN and AlCrN coated. TiN and AlCrN coated tools showed less wear than NCD and uncoated carbide tools and were abrasive. Burr width was minimum for TiN and AlCrN coated than the other and the diameter of the tools showed minimal change in values. Overall, the cutting performance of TiN and AlCrN was better in comparison.

2.3.3. MCD, SMCD, NCD and MCD/NCD composite coated carbide tools: Hua Wang et al [10], compared the cutting performances of MCD, SMCD, NCD and MCD/NCD composite coated carbide tools for the high-speed milling of hot bending graphite molds. The study indicated that the wear mechanism was due to abrasiveness of graphite. The study indicated that MCD has greater adhesiveness to Wc-Co than SMCD and NCD, but NCD showed less friction than the rest. Composite coating of MCD/NCD provided better surface smoothness and resistance to adhesiveness than the others thus resulting in machining efficiency and dimensional accuracy.

2.4. Uncoated and PVD Coated TiAlN & AlTiN coated tungsten carbide tools

Chakradhar Bandapalli et al [11], conducted a high-speed micro milling on grade 12 Ti alloy (Ti-0.3Mo-0.8Ni) to compare the tool wear of uncoated and PVD Coated TiAlN & AlTiN tungsten carbide tools. From the results it is stated that at a speed of 30000-70000 rpm, all the 3 tools shown less wear and at a higher speed of 70000-110000 the tool wear were in the ascending order as uncoated tungsten carbide, AlTiN coated tungsten carbide and TiAlN coated tungsten carbide.

2.5. Uncoated WC–Co and PCD inserts in titanium tools

A.K.M. Nurul Amin et al [12], replaced conventional titanium cutting tool with uncoated Wc-Co inserts and PCD inserts in titanium tool to perform Ti-6Al-4V alloy and compared the results based on applicable cutting speed ranges,metal removal per tool life,tool wear rate and morphology and vibrations produced. They concluded that at an acceleration of 120m/min the vibrations of the Wc-Co tool was lesser but with an increase in acceleration of 160 m/min and 200m/min PCD provided better results. The cross-sectional shape of the chip is directly proportional to chatter/vibration. At a axial depth of 1 mm,radial depth of 32mm and feed rate of 0.01mm the highest metal removal of metal per tool life occurred at 120m/min and 40m/min for PCD and carbide tools respectively and total metal removal rate occurred at 40-80m/min and 120-160m/min for Wc-Co and PCD respectively. Surface roughness was better at 120m/min for Wc-Co and at 160m/min for PCD. Thus, PCD was far better than uncoated carbide insert.

3. MATERIAL BEHAVIOUR

The machinability nature of the materials needs to be studied for selecting the appropriate tool and milling condition and they also provide a way to improve better finishing. Not all materials require high speed milling; certain materials which have high strength like super alloys require HSM.

3.1 Aluminium alloys

Hongbin Chang et al [13] Aluminium alloys play a vital role in the field of aerospace technology. High speed milling of Aluminium alloy can be made more efficient by using Ultra fine grain cemented carbide and the structure adhering the principle of minimal stress concentration , dynamic and static imbalance, reduce friction , improve the blade strength , reduce bending deformation to design. concentration , dynamic and static imbalance, reduce friction , improve the blade strength ,reduce bending deformation to design.

3.1.1 Aluminium semisolid 2024:

Surasit Rawangkong et al [14], studied the effects of surface roughness by using aluminum semi solid 2024 face milling by CNC milling machine and fine carbide tool with twin cutting edges.when higher the value of speed and lower the value of feed rate is to decrease surface roughness. The result shows the linear equation measurement value [Ra = 0.205 - 0.000022 Speed + 0.000031 Feed rate.] This equation is used with the speed in the range of 2,400 - 3,600 rpm, feed range of 1,000 - 1,500mm/min and depth of cut is not over 1 mm.

3.2. Inconel 718 (nickel-based alloy)

Sunil J Raykar et al [15], present the High-speed machining of Inconel 718 which is Nickel based heat resistant super alloy is used for analysing tool wear and surface roughness. Milling trials are conducted from low to high-speed ranges. It is found that in both speed ranges, the surface roughness values are the same as low speed as well as high speed. At both speed levels, no tool damages occur while machining of Inconel 718 which burn marks are visible on the tool; it is the major criteria that leads to tool wear.

3.3. Ti-6Al-4v and Ti-5553 alloy:

S. Vijay, V. Krishnaraj [16], optimization of end milling to analyse the parameters cutting speed, feed and depth of cut in Ti- 6Al-4v with the help of Taguchi method and ANOVA for designing this experiment. The result shows the depth of cut has a significant effect on cutting force followed by cutting speed and feed per tooth where surface roughness is followed by depth of cut and cutting speed. Asier Ugartea, b et al [4], Single tooth face milling was carried out with PVD coated cemented carbide tool to find the machining behaviour of titanium alloys such as Ti-6Al-4V mill annealed (MA), Ti-6Al-4V solution treated and aged (STA) and beta titanium alloy Ti-5553. These alloys generally show inherent properties such as

- Low thermal conductivity giving rise to high temperatures at the tool-chip and tool-work interfaces,
- The development of plastic instability and the formation of adiabatic shear bands causing high dynamic loads and tool vibration.
- A high chemical reactivity with many cutting tool materials causing rapid chemical wear by diffusion.

Which were used in aero parts making. The experiments were conducted, and results were observed that at cutting speed Vc= 40 m/min and feed rate 0.15mm/revolution, tool life was around 30mins and 26mins for Ti-6-4 (MA, STA) respectively and it was poor for Ti-5553. And also, with variation in dynamic load on the cutting tool, the above-mentioned results remained same. The rake temperature was around 660 deg celcius for Ti-55553 and around 550 deg celsius for Ti-6-4(MA). The overall result obtained was that the machinability of Ti-5553 was poor when compared to Ti-6-4(MA, STA).

3.4. Hardened Steel

Derzija Begic-Hajdarevic et al [17] In high speed milling of hardened steel with increase in cutting speed ,the surface roughness decreases, also the surface roughness increases with increase in feed per tooth .Feed per tooth has adverse effect on high speed machining.Greater tool diameter enhances the surface roughness.Minimal feed per tooth and low speed are the optimal conditions for machining Hardened Steel and cutter displacements increase with the increase in rotational speed which has an effect on centrifugal force growth[18].

4. CUTTING TOOL TEMPERATURE PREDICTION

It is most important to predict the tool temperature as it leads to tool wear and decrease in surface finish. This prediction will also give a brief detail on the selection of lubricant. Wu Baohai et al [19], present the paper to predict the cutting tool temperature prediction by two methods as analytical and theoretical methods. They considered, for temperature increase phase where real friction state between chip and tool, for temperature decrease phase 1D plate heat convection is proposed. The results suggest that tool temperature increases with the feed per tooth, and tool temperature decreases with cutting speed. The theoretical model for cutting tool temperature prediction further enhanced then used to optimize the cutting condition to prevent excessive tool wear in end milling.

5. LUBRICATION

5.1. Minimum Quantity Lubrication (MQL) Method

MQL is a method of spraying lubricant at the right area in a minimal amount rather than passing the lubricant/coolant fully over the machining surface. Y.S. Liao et al [20], conducted a HSM experiment on NAK80 hardened steel using a carbide tool to state the effectiveness of MQL in comparison with dry and flood cooling conditions. A low viscous oil with high fraction of low molecular weight under MQL condition produced fewer thermal cracks in the coating of the tool and delayed the welding of chips thus providing both good tool life and surface finish. But the dry and flood conditions resulted in thermal cracks and welding of chips.

5.1.1. Nano Mos2 Reinforced Vegetable Cutting Fluid: Alper Uysal et al [21], to study the effects of surface roughness and cutting Condition on initial tool wear by using Milling of AISI 420 Martensitic stainless steel. In this research MQL (Minimum Quantity Lubrication) is applied to vegetable cutting fluid and nano molybdenum disulphide fluid. They conducted the experiment at constant speed, depth of cut and feed rate. The two nanofluids 20ml/h and 40ml/h and pressure air mist are supplied by MQL.

The result shows that the tool wear and surface roughness are reduced by MQL method. By using nano MOS2 cutting fluid in MQL gives minimum tool wear and surface roughness.

5.1.2. Compressed col nitrogen gas: Y. Su et al [22], investigated the effects of lubrication conditions on tool wear in HSEM of Ti-6Al-4V with Walter ZDT150420R and TiN/TiCN/TiN coated carbide tools. The results were taken under: Compressed cold nitrogen gas and nitrogen mist and dry conditions. On the above CCNG and oil ist combination provided better results of tool wear with 2.69 times better than dry condition and 1.93 times better than nitrogen mist conditions. MQL is more suitable than flood type coolant systems especially for this titanium alloy.

5.2. Electrostatic minimum quantity lubrication (EMQL):
Though MQL produced best results the oil mist concentration produced in the process mixes in the ambient air thus resulting in health of the worker.

5.2.1. SiO2 based water lubricant: Tao Lv et al [23], in their paper used SiO2 water-based nano-lubricants. At the voltage of -4 kV, PM10 = 0.9 mg / m3, PM2.5 =0.52 mg / m3, it showed lowest mist concentration thus meeting the safety standards and showed higher charging capacity, better adsorption, and deposition qualities. Though its inclusion lowered the cutting force, it did not affect the overall performance exhibited by the earlier method. The surface smoothness also improved than that of MQL. Thus, it provided a feasible solution leaving minimal droplets in its environment without affecting the workers.

5.3. Cryogenic cooling: A. Shokrania et al [24] It is reported that the effects of cryogenic cooling on the machinability of Inconel 718 by using PVD TiAlN coated solid carbide end mills has more benefits than the dry machining. It improves the surface finish of the material but has an adverse effect on the tool life as it results in tool failure.

6. SURFACE ROUGHNESS AND VIBRATION

Roughness in the surface of the product may lead to undesired performance results and it also costs grinding operation to be performed. To overcome this along with cutting and cooling parameters roughness and vibration are analysed alongside. Mohamed Zakaria Zahaf et al [25], tested shoulder and contour milling of AISI 52100, which is commonly used in manufacturing mechanical parts, in its two variants such as annealed and hardened with coated TiN, TiCN inserts to determine the surface roughness and vibrations. Shoulder and contour milling will always have high axial depth of cut and low radial depth of cut. With the results they stated that these tool inserts are suitable for industrial applications. Down milling is preferred for such applications. For annealed steel, depth of cut affects vibration more than cutting speed and feed rate. But hardened steel cutting speed is the most influential parameter which interferes increase in hardness, increases the vibration, and decreases the tool life. Also, they stated that coated tools are more cost efficient than the grinding process for surface finish. With mathematical calculation used and the input parameters they introduced a term named desirability factor, which is 0.8 for AISI 52100. Satyam B Patel et al [26], presented the surface roughness and Material removal rate of CNC Milling machine in stainless steel from the required parameters such as Spindle speed, feed rate, depth of cut and nose radius. In this study they use RSM (Response Surface Methodology) to produce better surface finish in Milling operation, which is a more effective and efficient method for surface roughness.

7. ADVANCEMENT IN AUTOMATED HSM

Automation has taken its part in the manufacturing sectors to increase productivity, providing better machining, decreasing process time and labour, and automated tool path generation techniques have been evolved over the years to decrease the losses. Such milling processes include 5 axis flank milling, trochoidal milling and epicycloidal milling.

7.1 Five axis flank milling:
Wenyao Shao et al [27], is to generate the tool path for five axis flank milling; they considered the dynamic characteristics of the machine tool. A corner is built according to part model and roughing information where the corner is stable. Clothoid curve and milling force is constrained. The materials are unevenly distributed in corners. The cutting force is constrained by limiting the cutting width during the machining process.and to change the tool path curvature is satisfied by the dynamic characteristics of the machine tool by using clothoid curve. Ke Xu et al [27] discussed the advantages of 5 axis flank milling over other milling processes in it's fine surface finish. The papers which were the predecessor to this journal focused only on decreasing geometric error for good surface finish, but those algorithms were big and heavy load to the compilers. To overcome this defect an alternative algorithm is proposed which involves improved tool path generation to have a linear interpolation in the machine coordinate system. An eight bladed impeller is designed, and 5 axis flanks process simulation is done with a cylindrical cutter with this algorithm and the favoured results were obtained.

- Cutter location after using linear interpolation method.
- Error map which shows the minimal error occurrence.

7.2. Epicycloidal and Trochoidal milling
B. Fath et al [28], they presented their paper for maximum efficiency and reducing machine cycle time in trochoidal milling while the navel tool path is in epicycloidal milling. They considered two strategies (I) optimization of cutting parameters (ii) selection of optimum tool path. From these two strategies to compare cutting speed, machine cycle time and tool tip vibrations. The cutting force and vibration increase from trochoidal and ending epicycloidal strategy. The machine cycle time is reduced by using epicycloidal strategy.

7.3 Specification of process based on applications:
In modern days different industries need different milling/machining techniques and the conventional type of selection is not suitable. Therefore, the entire data is fed into the system, and we can have access to select the suitable data for the machine to perform.

7.3.1. Cutting parameters selection in milling for aero parts: Youngfeng Hou et al [29] This paper states the parameters on what the CNC milling, which is a high-speed machining process, depends on and how they can be specifically updated to the CNC machine. The aero engine parts design is of complex structures and any deviation in surface finish and design can affect engine performance. Certain materials like titanium alloy, ceramic based alloys etc are used. The paper also includes some matrices such as,

- Machine tool matrix Mt= {P, T,nmax, fmax,Pr} which includes power, spindle torque, maximum speed of revolution, maximum feed rate and position precision respectively.
- Cutting tool matrix T = $\{r, Rc, Rr, Rz, a, b, h, z, \gamma_0, \alpha_0, \beta\}$ which involves rake angle, crank angle, and helix angle
- Workpiece material matrix M = {HRC, E, G, μ, ρ, σ_s, σ_b, k} which has Rockwell hardness, elastic modulus, shear modulus, density, shear stress, tensile stress and thermal conductivity respectively.
- Cooling matrix C = $\{S, p, L, t\}$ which includes cooling mode, pressure, flow rate and temperature, respectively.
- Part feature F = {C, Lf} which includes machining procedure and machining method.
- Condition vector Cc = {Mt, T, M, C, F, P} which has the above said matrices as a sub matrix.

Certain process parameter vectors such as spindle speed of revolution, cutting depth and width and feed rate are added. And the difference vector and weight matrix which depends on the size of the part to be milled are added. An experiment was done on a model and process condition vector, process parameter vector, actual process condition vector is obtained with desired results.

8. CONCLUSION

Need for composites and super alloys are increasing in the modern era. Therefore, High speed milling has its impact in almost all the industries such as automobile, aerospace, medical etc. As automation is the new normal kind of manufacturing in the future, it is important to improve HSM in some areas. Those areas include the tool path generation in the CNC machines which must be very simple for the user to understand and access and for the machine to compile it easily. Error correction in the CNC process is quite complicated and those things may have a bit of improvement. Though super alloys are milled with greater quality there is lag in the surface finish when micro milling is concerned. If those disadvantages are met in future manufacturing will be led to another level of excellence.

9. REFERENCES

[1]. H. Schulz, Hochgeschwindigkeits-bearbeitung, Carl Hanser Verlag Munchen, Wein, 1996.

[2]. R. Pasko, L. Przybylski, and B. Slodki, “High speed machining (HSM) – the effective way,” *Int. Work. CA Syst. Technol.*, no. January 2002, pp. 72–79, 2017.

[3]. A. Teo, S. Danielson, and T. Georgeou, “High performance machining: A practical approach to high-speed machining,” *ASEE Annual. Conf. Expo. Conf. Proc.*, 2008, doi: 10.18260/1-2--3816.

[4]. R. B. Da Silva, Á. R. MacHado, E. O. Ezugwu, J. Bonney, and W. F. Sales, “Tool life and wear mechanisms in high-speed machining of Ti-6Al-4V alloy with PCD tools under various coolant pressures,” *J. Mater. Process. Technol.*, vol. 213, no. 8, pp. 1459–1464, 2013, doi: 10.1016/j.jmatprotec.2013.03.008.

[5]. M. Sajgalik *et al.*, “Identification of Technological Parameters when Machining Ni-Alloys by Monolithic Ceramic Milling Tool,” *Procedia Manuf.*, vol. 14, pp. 51–57, 2017, doi: 10.1016/j.promfg.2017.11.006.

[6]. D. Grguraš, M. Kern, and F. Pušavec, “Suitability of the full body ceramic end milling tools for high-speed machining of nickel-based alloy Inconel 718,” *Procedia CIRP*, vol. 77, no. Hpc, pp. 630–633, 2018, doi: 10.1016/j.procir.2018.08.190.

[7]. A. Çelik, M. Sert Alağaç, S. Turan, A. Kara, and F. Kara, “Wear behavior of solid SiAlON milling tools during high-speed milling of Inconel 718,” *Wear*, vol. 378–379, pp. 58–67, 2017, doi: 10.1016/j.wear.2017.02.025.

[8]. C. Y. Wang, Y. X. Xie, Z. Qin, H. S. Lin, Y. H. Yuan, and Q. M. Wang, “Wear and breakage of TiAlN- and TiSiN-coated carbide tools during high-speed milling of hardened steel,” *Wear*, vol. 336–337, pp. 29–42, 2015, doi: 10.1016/j.wear.2015.04.018.

[9]. K. Aslantas, H. E. Hopa, M. Percin, I. Ucun, and A. Çicek, “Cutting performance of nano-crystalline diamond (NCD) coating in micro-milling of Ti6Al4V alloy,” *Precis. Eng.*, vol. 45, pp. 55–66, 2016, doi: 10.1016/j.precisioneng.2016.01.009.

[10]. H. Wang, J. Yang, and F. Sun, “Cutting performances of MCD, SMCD, NCD and MCD/NCD coated tools in high-speed milling of hot bending graphite molds,” *J. Mater. Process. Technol.*, vol. 276, no. February 2019, p. 116401, 2020, doi: 10.1016/j.jmatprotec.2019.116401.

[11]. C. Bandapalli, B. M. Sutaria, D. V. Prasad Bhatt, and K. K. Singh, “Tool wear analysis of micro end mills - Uncoated and PVD coated TiAlN & AlTiN in high-speed micro milling of titanium alloy - Ti-0.3Mo-0.8Ni,” *Procedia CIRP*, vol. 77, no. Hpc, pp. 626–629, 2018, doi: 10.1016/j.procir.2018.08.191.

[12]. A. K. M. N. Amin, A. F. Ismail, and M. K. Nor Khairusshima, “Effectiveness of uncoated WC-Co and PCD inserts in end milling of titanium alloy-Ti-6Al-4V,” *J. Mater. Process. Technol.*, vol. 192–193, pp. 147–158, 2007, doi: 10.1016/j.jmatprotec.2007.04.095.

[13]. Hongbin Chang, Suyun Li, Runping Shi 13th Global Congress on Manufacturing and Management, GCMM 2016 Procedia Engineering 174 (2017) 630 – 637

[14]. S. Rawangwong, J. Chatthong, W. Boonchouytan, and R. Burapa, “An investigation of optimum cutting conditions in face milling aluminum semi solid 2024 using carbide tool,” *Energy Procedia*, vol. 34, pp. 854–862, 2013, doi: 10.1016/j.egypro.2013.06.822.

[15]. D. M. D’Addona, S. J. Raykar, and M. M. Narke, “High Speed Machining of Inconel 718: Tool Wear and Surface Roughness Analysis,” *Procedia CIRP*, vol. 62, pp. 269–274, 2017, doi: 10.1016/j.procir.2017.03.004.

[16]. S. Vijay and V. Krishnaraj, “Machining parameters optimization in end milling of Ti-6A1-4V,” *Procedia Eng.*, vol. 64, pp. 1079–1088, 2013, doi: 10.1016/j.proeng.2013.09.186.

[17]. Derzija Begic-Hajdarevic*, Ahmet Cekic, Malik Kulenovic 24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013 Procedia Engineering 69 (2014) 291 – 295
[18]. PAWEŁ" TWARDOWSKI 1,SZYMON WOJCIECHOWSKI 1,MICHA" WIECZOROWSKI 1, AND THOMAS MATHIA 2 SCANNING VOL. 33, 386–395 (2011)
[19]. W. Baohai, C. Di, H. Xiaodong, Z. Dinghua, and T. Kai, "Cutting tool temperature prediction method using analytical model for end milling," *Chinese J. Aeronaut.*, vol. 29, no. 6, pp. 1788–1794, 2016, doi: 10.1016/j.cja.2016.03.011.
[20]. Y. S. Liao, H. M. Lin, and Y. C. Chen, "Feasibility study of the minimum quantity lubrication in high-speed end milling of NAK80 hardened steel by coated carbide tool," *Int. J. Mach. Tools Manuf.*, vol. 47, no. 11, pp. 1667–1676, 2007, doi: 10.1016/j.ijmachtools.2007.01.005.
[21]. A. Uysal, F. Demiren, and E. Altan, "Applying Minimum Quantity Lubrication (MQL) Method on Milling of Martensitic Stainless Steel by Using Nano Mos2 Reinforced Vegetable Cutting Fluid," *Procedia - Soc. Behav. Sci.*, vol. 195, pp. 2742–2747, 2015, doi: 10.1016/j.sbspro.2015.06.384.
[22]. Y. Su, N. He, L. Li, and X. L. Li, "An experimental investigation of effects of cooling/lubrication conditions on tool wear in high-speed end milling of Ti-6Al-4V," *Wear*, vol. 261, no. 7–8, pp. 760–766, 2006, doi: 10.1016/j.wear.2006.01.013.
[23]. T. Lv, X. Xu, A. Yu, and X. Hu, "Oil mist concentration and machining characteristics of SiO2 water-based nano-lubricants in electrostatic minimum quantity lubrication-EMQL milling," *J. Mater. Process. Technol.*, vol. 290, no. October 2020, p. 116964, 2021, doi: 10.1016/j.jmatprotec.2020.116964.
[24]. A. Shokrania,*, V. Dhokiaa , S.T Newmana , R. Imani-Asraia Procedia CIRP 3 (2012) 121 – 125 2212-8271 doi: 10.1016/j.procir.2012.07.022 45th CIRP Conference on Manufacturing Systems 2012
[25]. M. Z. Zahaf and M. Benghersallah, "Surface roughness and vibration analysis in end milling of annealed and hardened bearing steel," *Meas. Sensors*, vol. 13, no. September 2020, p. 100035, 2021, doi: 10.1016/j.measen.2020.100035.
[26]. P. S. P. Patel. H. B, "A Review Paper for Optimization of Surface Roughness and MRR in CNC Milling," *Int. J. Res. Mod. Eng. Emerg. Technol.*, vol. 1, no. 5, pp. 23–29, 2013.
[27]. W. Shao, Y. Li, C. Liu, and X. Hao, "Tool Path Generation Method for Five-axis Flank Milling of Corner by Considering Dynamic Characteristics of Machine Tool," *Procedia CIRP*, vol. 56, pp. 155–160, 2016, doi: 10.1016/j.procir.2016.10.046.
[28]. K. Xu, J. Wang, C. H. Chu, and K. Tang, "Cutting force and machine kinematics constrained cutter location planning for five-axis flank milling of ruled surfaces," *J. Comput. Des. Eng.*, vol. 4, no. 3, pp. 203–217, 2017, doi: 10.1016/j.jcde.2017.02.003.
[29]. M. Salehi, M. Blum, B. Fath, T. Akyol, R. Haas, and J. Ovtcharova, "Epicycloidal Versus Trochoidal Milling-Comparison of Cutting Force, Tool Tip Vibration, and Machining Cycle Time," *Procedia CIRP*, vol. 46, pp. 230–233, 2016, doi: 10.1016/j.procir.2016.04.001.
[30]. Y. Hou, D. Zhang, M. Luo, and B. Wu, "A cutting parameters selection method in milling aero-engine parts based on process condition matching," *Adv. Mech. Eng.*, vol. 2013, 2013, doi: 10.1155/2013/157343

