International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:4, No:11, 2010

Effect of Dry Cutting on Force and Tool Life When Machining Aerospace Material

K.Kadirgama[1], M.M.Noor[1], K.A. Abou-El-Hossein[2], H.H.Habeeb[3], M.M. Rahman[1], B.Mohamad[3], R.A. Bakar[1]

***Abstract*—**Cutting fluids, usually in the form of a liquid, are applied to the chip formation zone in order to improve the cutting conditions. Cutting fluid can be expensive and represents a biological and environmental hazard that requires proper recycling and disposal, thus adding to the cost of the machining operation. For these reasons dry cutting or dry machining has become an increasingly important approach; in dry machining no coolant or lubricant is used. This paper discussed the effect of the dry cutting on cutting force and tool life when machining aerospace materials (Haynes 242) with using two different coated carbide cutting tools (TiAlN and TiN/MT-TiCN/TiN). Response surface method (RSM) was used to minimize the number of experiments. ParTiAlN Swarm Optimisation (PSO) models were developed to optimize the machining parameters (cutting speed, federate and axial depth) and obtain the optimum cutting force and tool life. It observed that carbide cutting tool coated with TiAlN performed better in dry cutting compared with TiN/MT-TiCN/TiN. On other hand, TiAlN performed more superior with using of 100 % water soluble coolant. Due to the high temperature produced by aerospace materials, the cutting tool still required lubricant to sustain the heat transfer from the workpiece.

***Keywords*—**Dry cutting, partial swarm optimisation, response surface method, tool life

I. Introduction

NICKEL-based alloy 242 has been widely used in the aircraft and nuclear industry due to its exceptional thermal resistance and the ability to retain its mechanical properties at elevated temperatures over 700 °C [1-3]. Nickel based alloys are classified as difficult to cut materials due to their high shear strength, work hardening tendency, highly abrasive carbide particles in the microstructure, strong tendency to weld and form a built-up edge BUE and low thermal conductivity [4,5]. They have a strong tendency to maintain their strength at the high temperature that is generated during machining [6]. Short tool life and surface quality problems during machining of nickel based alloys are main subjects that must be investigated. Residual stresses formed at work-piece surface during machining negatively affect the mechanical strain and corrosion properties of the work-piece [2, 5]. The three main factors that affect the performance of a cutting tool whilst machining nickel alloys are high hardness, wear resistance, chemical inertness and fracture toughness.

Cutting fluids, usually in the form of a liquid, are applied to the chip formation zone in order to improve the cutting conditions. These improvements can take several forms, depending on the tool and work materials. Normally cutting fluid is used to reduce friction and wear (hence improving tool life and surface finish), to reduce cutting forces and energy consumption, to cool the cutting zone (thus reducing workpiece temperature and distortion), to wash away chips and to protect newly machined surfaces from environmental corrosion [7, 8].Cutting fluid can be expensive and represents a biological and environmental hazard that requires proper recycling and disposal, thus adding to the cost of the machining operation. For these reasons dry cutting or dry machining has become an increasingly important approach; in dry machining no coolant or lubricant is used [7, 8].Even though this approach suggests that higher temperature and more rapid tool wear will occur, some tool materials and coatings exhibit a reasonable tool life at higher temperature. Dry cutting, sometimes, is associated with high-speed machining, because higher cutting speed condition conveys a great amount of heat to the chip, which is a natural strategy to reduce the need for a coolant [7 – 9]. Large machining centers often have a coolant station that is very complex. The coolant station provides coolant through the tools in order to increase the amount of fluid for cutting operation. Coolant stations are usually made up of a series of filters to remove impurities and chips that have been carried in the coolant and pumps. Some coolant stations provide pressures of more than 1000 psi to the cutting operation. The relatively high pressure value allows good removal of chips, significant cooling, and better surface finish [10]. The cutting speed, the feed rate, and the depth of cut are the selected machining parameters, which influence the machining process to great extent [11 – 14]. Lin and Chananda [15] improved the injection-molding quality by a four-factor full-factorial design. In this study, an optimized parameter setting was identified from the regression models that relate the desired outputs and the controlled inputs. Puertas and Luis [16] applied the DOE method to optimize the machining parameters for electrical discharge machining of

K.Kadirgama is with the University Malaysia Pahang, Tun Razak Highway, 46300 Pahang, Malaysia (Phone: +609-4242239; fax: +609-4242202; e-mail: kumaran@ump.edu.my).

M.M.Noor is with the University Malaysia Pahang, Tun Razak Highway, 46300 Pahang, Malaysia (Phone: +609-4242237; fax: +609-4242202; e-mail: Muhamad@ump.edu.my).

boron carbide. Alagumurthi *et al.* [17] applied the DOE method to determine optimal settings of grinding conditions and grinding cycle time for which results were compared and analyzed. In the present study, the optimisation of the cutting parameters (cutting speed, federate and axial depth) for dry cutting of Haynes 242 through partial swarm optimisation was found.

II. Partial swarm optimazations

PSO algorithm is similar to that of the evolutionary computation techniques in which a population of potential solutions to the optimal problem under consideration is used to probe the search space. Each potential solution is also assigned a randomized velocity, and the potential solutions, called *particles*, correspond to individuals. Each particle in PSO flies in the *D*-dimensional problem space with a velocity dynamically adjusted according to the flying experiences of its individuals and their colleagues. The location of the *i*th particle is represented as $X_i=[x_{i1}, x_{i2},\ldots, x_{iD}]$, where $x_{id} \in [I_d,u_d]$, $d \in [1,D]$, I_d,u are the lower and upper bounds for the d^{th} dimension, respectively. The best previous position (which gives the best fitness value) of the i^{th} particle is recorded and represented as $P_i=[p_{i1}, p_{i2},\ldots, p_{iD}]$, which is also called P_{best} . The index of the best particle among all the particles in the population is represented by the symbol g . The location P_g is also denoted by g_{best} . The velocity of the i_{th} particle is represented by $V_i=[v_{i1}, v_{i2},\ldots, v_{iD}]$ and is clamped to a maximum velocity $V_{max}=[v_{max1}, v_{max2},\ldots, v_{maxD}]$, which is specified by the user. The particle swarm optimization concept consists of, at each time step, regulating the velocity and location of each particle toward its P_{best} and g_{best} locations according to the Eqns. (1) and (2), respectively [18].

$$v_{id}^{n+1} = wv_{id}^{n} + c_1 r_1^{n}(p_{id}^{n} - x_{id}^{n}) + c_2 r_2^{n}(p_{gd}^{n} - x_{id}^{n}) \quad (1)$$

$$x_{id}^{n+1} = x_{id}^{n} + v_{id}^{n+1} \quad (2)$$

The PSO outputs have been termed as one output node representing the state variable (tool life and cutting force) as shown in Figure 1. The experimental results are used for the optimisation of the tool life model using the PSO. The codes for the PSO are written in Matlab 7.0 which follows the logic of the pseudocode shown in Figure 2. According to Jialin Zhou *et al.*[19] particle swarm optimization (PSO) technique perform than back propagation (BP) algorithms when predict the diameter error in a boring machining. To overcome the stagnation in searching a globally optimal solution, a PSO method with nonlinear time-varying evolution (PSO-NTVE) is proposed to approach the optimal solution closely. When determining the parameters in the proposed method, matrix experiments with an orthogonal array are utilized, in which a minimal number of experiments would have an effect that approximates the full factorial experiments [20]. Ying-Pin Changa and Chia-Nan Ko [21] proposed a method with nonlinear time-varying evolution based on neural network (PSO-NTVENN) to design large-scale passive harmonic filters (PHF) under abundant harmonic current sources. The goal is to minimize the cost of the filters, the filters loss, and the total harmonic distortion of currents and voltages at each bus, simultaneously. The performance of PSO for function optimization in noisy environment is investigated, and an effective hybrid PSO approach named PSOOHT is proposed by Hui Pan *et al.* [22].

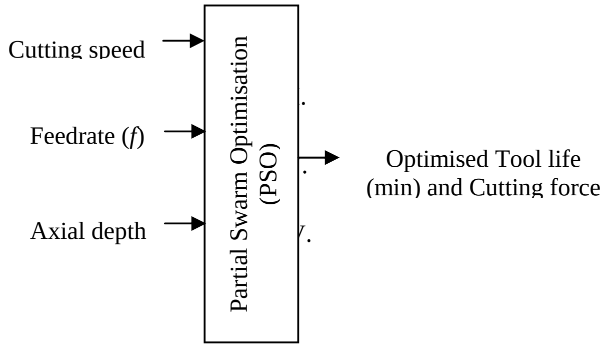

Fig. 1 PSO for paddle cantilever

```
For each particle
   Initialize particle
END

Do
   For each particle
      Calculate fitness value
      If the fitness value is better than the
best fitness value (pBest) in history
         set current value as the new pBest
   End
   Choose the particle with the best fitness
value of all the particles as the gBest
   For each particle
      Calculate particle velocity according
equation (a)
      Update particle position according
equation (b)
   End
```

Fig. 2 A pseudo-code for PSO

III. Experimental study

A computer numerical controlled (CNC) machine center with a speed range from 250 to 1000 rpm was used for the machining trials. The machine center is driven by a 7.5 kW stepless motor which provides high torque. A vertical machine center OKUMA MX45-VA was used for all operations that preparing the workpiece or cutoff were required. This was rigid and high precision machine that was suitable for milling as shown in Figure 3a. Machining trials were conducted using 23 x 110 x 170 mm, age hardened nickel based alloys 242 workpiece. A Kistler force dynamometer model 9275B was used to record cutting force during experimental milling operations. Model 5004 Kistler dual mode charge amplifiers were used to convert the dynamometer output signal into a voltage signal appropriate for the data acquisition system. The input sensitivities of the charge amplifier were set corresponding to the output sensitivity of the force dynamometer in the direction of the forces. Cutting inserts coated carbide grade with a TiAIN (PVD – KC520M) and coated carbide grade with a CVD multilayer coating (TiN/MT-TiCN/TiN – KC915M) were used. KC520M carbide grade developed specificially for general machining of ductile cast iron. This grade can be used wet and dry. Meanwhile KC 915M is a universal grade for milling cast iron. This cutting material is the first choice for light and general machining. KC 915 can be used dry and wet machining. The geometry parameters of the tool were controlled accordingly to International organization for Standardization (ISO) SPHX1205ZCFRGN1W as shown in Figure 3b. The nose radius of the inserts is 90°, clearance angle 11° and positive rake angle. TiAlN and TiN coated tool mounted on tool holder with shoulder angle 70° is employed as shown in Figure 3c. The tool holder provided a cutting diameter of 50 mm. In this study, cutting speed, feedrate and axial depth were varied. The ranges of these parameters are shown in Table 1. First test was done without using any coolant and lubrication. After that, second test was conducted with coolant to investigate the performance of the cutting tools with application of coolant. The high-pressure coolant was supplied by an external high powered pump at a flow rate range and directed via a nozzle on the tool holder to the region where the chip breaks contact with the tool. The experiments were carried out until an area of 0.3 mm wear on the flank face was reached. Wear progression was observed using an optical microscope equipment with an image analyzer. In addition, scanning electron microscope was used for further investigation of the wear mechanisms. Three cutting conditions (cutting speed, feedrate, axial depth of cut) were set three levels; high, medium and low values. The radial depth of cut was held constant while the axial depth was varied at three levels. The experiments were conducted as shown in Table 2 which derived from statistical software.

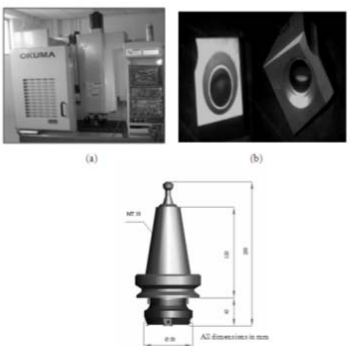

Fig. 3 (a) CNC OKUMA MX45-VA; (b) Cutting tools; (c) Tool holder

TABLE I
LEVELS OF INDEPENDENCE VARIABLES

Level	Low	Medium	High
Coding	-1	0	0
Speed V_c (rpm)	250	625	1,000
Feed f (mm/rev)	0.1	0.2	0.3
Axial Depth d_a(mm)	0.4	0.7	1

TABLE II
DESIGN OF EXPERIMENTS

Cutting speed (m/min)	Feedrate (mm/rev)	Axial depth (mm)
62.5	0.3	0.4
62.5	0.1	0.4
25.0	0.2	0.4
100.0	0.2	0.4
62.5	0.2	0.7
62.5	0.2	0.7
25.0	0.1	0.7
100.0	0.1	0.7
25.0	0.3	0.7
62.5	0.2	0.7
100.0	0.3	0.7
25.0	0.2	1.0
100.0	0.2	1.0
62.5	0.1	1.0
62.5	0.3	1.0

IV. RESULT AND DISCUSSION

Generally, cutting tool materials are exposed to high mechanical stresses and thermal disturbances when machining nickel based alloys resulting in cutting tool wear and short tool life. The most known tool wear type while cutting the nickel based alloys is flank wear formed at the depth of cut due to high thermal combinations, high work hardness, high strength of the work-piece and abrasive particles [2,5,23,24]. Flank wear, chipping and severe damages are the causes of tool wear. In some literature studies, TiAIN cutting tools are suitable for the machining of nickel based alloys at the cutting speeds between 200 m/min and 750 m/min employed low cutting depth [1,2,24,25]. The rate of wear and characteristics of TiAlN and TiN/MT-TiCN/TiN cutting tool were examined until reached to standard wear limit (0.3 mm) using a high magnification microscope model Nikon Optiphot-100. All cutting tools passes tests examined after machining of the workpiece at the length of cutting pass 90mm. After the first pass of machining and the analysis will be carry out by considering the rate of progress wear for that particular test. Figure 4a and 4b shows the tool life and the cutting force results which obtain from experiments. It observed that TiAlN performed better than TiCN/TiN in terms of tool life and cutting force. The inserts particularly give good results when machining with coolant. In other hand, dry cutting produce high cutting force and low tool life compare with coolant. It is observed that the wear on the cutting edge is uniform; the chipping is occupied the contact area. This assisted due to the physical property of titanium and nitride coating layers which provides a low thermal conductivity [26]. The low thermal conductivity of titanium and nitride coating else assisted to decrease the wear rate at cutting edge of the tools when using these cutting conditions. Particle parts observed on the cuttingedge, and further machining caused sticking of particle chips on the flank face. Tools that are coated by, TiN/MT-TiCN/TiN demonstrated less resistance to wear progression compared with tools coated by TiAlN. However all tools suffered the formation of the build-up edge as shown in Figure 5a. This phenomenon is very common when machining nickel alloys. Most of the cutting tool from the dry cutting suffered with high crack and some of the inserts damage. The crack and the damage cutting tool are shown in Figure 5b for both coated carbide.

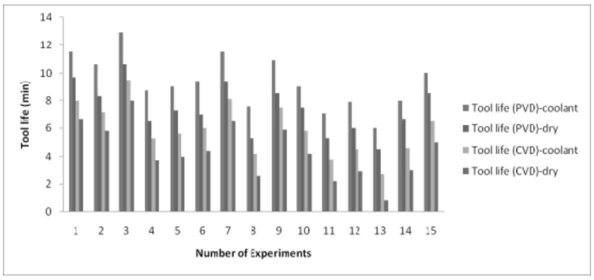

Fig. 4a Tool life experimental results

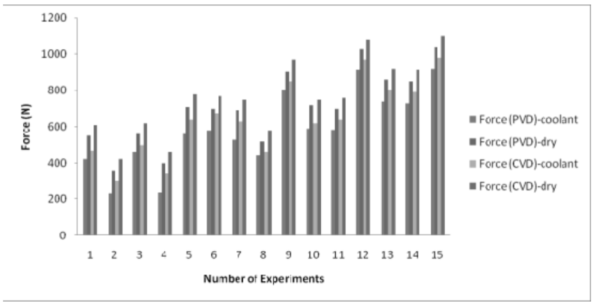

Fig. 4b Force experimental results

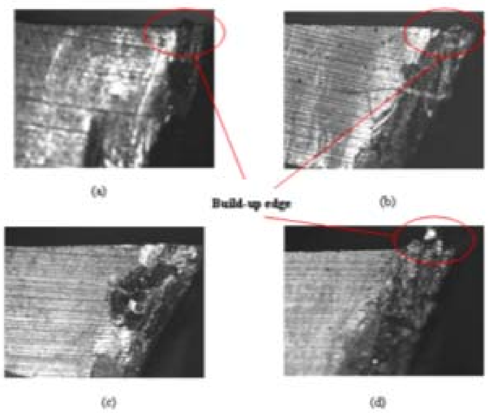

Fig. 5 (a) Build-up edge

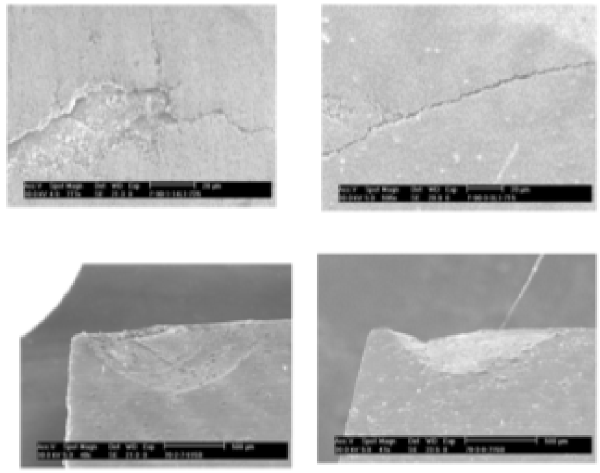

Fig. 5 (b) Crack and tool damaged in dry cutting for both coated tools

A. Other Recommendations

Eventhough the dry cutting results not as fine as coolant but under certain conditions it still produces satisfaction results. Partial swarm optimisation (PSO) was used to find the maximum tool life and minimum cutting force. The validation experiment is performed in the same machining environment as the training experiment. The optimum parameters as suggested by PSO produced 378 N of force and 7.98 min of tool life for TiN/MT-TiCN/TiN. The error of tool life and cutting force for TiN/MT-TiCN/TiN obtained by optimised tool life model is 1.82% and 1.48 %. It observed that, when applying the optimum parameters (cutting speed = 25 m/min, federate = 0.1 mm/rev and axial depth = 0.4 mm) for tool life the measured cutting force at this stage is 522 N. Meanwhile for optimum parameters for cutting force, it observed that the measured tool life is 3.95 min. In other hand, for TiAlN the optimum tool life and cutting tool suggested by PSO were 10.53 min and 283 N. The error of tool life and cutting force for TiN/MT-TiCN/TiN obtained by optimised tool life model is 5.19% and 2.13 %. When applying the optimum parameters (cutting speed = 25 m/min, federate = 0.1 mm/rev and axial depth = 0.4 mm) for tool life, the measured cutting force is 461 N. The optimum parameters for cutting force produced 6.68 min of tool life. It observed that, eventhough the optimum parameters produce acceptable cutting force and tool life but it reflects in other parameters such as produce high cutting force and low tool life.

V. Result and Discussion

This research illustrates the machining of Haynes 242 with end-milling methods and predicting their subsequent tool life and cutting force. There is becoming a need for investigating the machining of various types of aerospace materials and their tool life which in turn can be useful in developing more cost effective personalised products. The authors have shown the use of PSO to formulate an optimised tool life and cutting force prediction model for end machining of Haynes 242 aerospace material. This prediction model is tested on the validation experimental and the error analysis of the prediction result with the measured results is estimated as 1.48 % to 5.13 % which is small and shows the efficacy of the prediction model. Generally, flank wear is the wear mechanisms observed with TiAlN and TiN/MT-TiCN/TiN inserts. The dominant wear mechanisms are seen at flank face of cutting tools and all the tools suffered the formation of the build-up edge. TiAlN inserts showed good performance when using dry cutting compare with TiN/MT-TiCN/TiN inserts. The performance of the cutting tools double up when coolant was used.

ACKNOWLEDGMENT

The authors would like to express their deep gratitude to Universiti Tenaga Nasional (UNITEN) for providing the laboratory facilities and University Malaysia Pahang (UMP) for financial support (RDU 080324).

REFERENCES

[1] Richards N, Aspinwall D. Use of ceramic tools for machining nickelbased alloys. Int J Mach Tool Manf 1989;294:575–88.
[2] Khamsehzadeh H. Behaviour of ceramic cutting tools when machining superalloys. Ph.D. thesis, University of Warwick; 1991. p. 125.
[3] Ezugwu EO, Machado AR, Pashby IR, Wallbank J. The effect of high-pressure coolant supply. Lub Eng 1990;479:751–7.
[4] Ezugwu EO, Wang ZM. Performance of PVD and CVD coated tools when nickel-based machining Inconel 718 alloy. In: Narutaki N, et al., editors. Progress of cutting and grinding; 1996. p. 111:102–7.
[5] Wang ZM. Titanium alloys and their machinability with coated carbide inserts. Ph.D. thesis, South Bank University, London, UK; 1997. p. 78–9, 247.
[6] Li L, He N, Wang M, Wang ZG. High speed cutting of Inconel 718 with coated carbide and ceramic inserts. J Mater Process Technol 2002;129:127–30.
[7] Metal cutting theory and practice by David a. Stephenson and John S.Agapiou, publish by Marcel Dekker, Inc, 1997.
[8] Metal Cutting Mechanics by Viktor P.Astakhov, publish by CRC press, 1999.
[9] Manufacturing Process and Systems, Ninth Edition; by Philip F.Ostwald and Jairo Munoz, publish by John Wiley & Son.
[10] Workshop Technology Volume 2; by HS Bawa;publish by Tata McGraw-Hill;1995.
[11] Alauddin, M., Baradie, M.A.E., Hashmi, M.S.J., 1995. Computer-aided analysis of a surface-roughnessmodel for endmilling. J.Mater. Process. Technol. 55, 123–127.
[12] Davim, J.P., 2003. Design of optimization of cutting parameters for turning metal matrix composites based on the orthogonal arrays. J. Mater. Process. Technol.132, 340–344.
[13] Ghani, J.A., Choudhury, I.A.,Hassan,H.H., 2004. Application of Taguchi method in the optimization of end milling parameters. J. Mater. Process. Technol. 145, 84–92.
[14] Reddy, N.S.K., Rao, P.V., 2005. Experimental investigation to study the effect of solid lubricants on cutting forces and surface quality in endmilling. Int. J.Mach. Tools Manuf. 45, 1–10.
[15] Lin, T., Chananda, B., 2004. Quality improvement of an injection-molded product using design of experiments: a case study. Qual. Eng. 16 (1), 99–104.
[16] Puertas, I., Luis, C.J., 2004. A study of optimization of machining parameters for electrical discharge machining of boron carbide. Mater. Manuf. Process. 19 (6),1041–1070.
[17] Alagumurthi, N., Palaniradja, K., Soundararajan, V., 2006. Optimization of grinding process through design of experiment (DOE)—a comparative study. Mater.Manuf. Process. 21 (1), 19–21.
[18] Yijian Liu, Xiongxiong He "Modeling Identification of Power Plant Thermal Process Based on PSO Algorithm" American Control Conference, Portland, USA, June 8-10, 2005.
[19] Jialin Zhou, Zhengcheng Duana, Yong Lia, Jianchun Denga and Daoyuan Yua," PSO-based neural network optimization and its utilization in a boring machine", Journal of Materials Processing Technology,178(1-3), pp.19 – 23. doi:10.1016/j.jmatprotec.2005.07.002.
[20] Chia-Nan Koa,Ying-Pin Changb, and Chia-Ju Wuc," An orthogonal-array-based particle swarm optimizer with nonlinear time-varying evolution", Applied Mathematics and Computation, 191(1), pp. 272 – 279. doi:10.1016/j.amc.2007.02.096.
[21] Ying-Pin Changa and Chia-Nan Kob," A PSO method with nonlinear time-varying evolution based on neural network for design of optimal harmonic filters", Expert Systems with Applications, 36(3), pp. 6809-6816. doi:10.1016/j.eswa.2008.08.007.
[22] Hui Pan, Ling Wanga and Bo Liu," Particle swarm optimization for function optimization in noisy environment", Applied Mathematics and Computation, 181(2), pp. 908 – 919. doi:10.1016/j.amc.2006.01.066.
[23] Bhattacharya SK, Pashby IR, Ezugwu EO. Machining of INCO 718 and INCO 901 superalloys with Sic-whisker reinforced Al2O3 composite ceramic tools. Prod Eng 1987:176–81.
[24] Bhattacharya SK, Jawid A, Lewis MH. Behaviour of sialon ceramic tools when machining cast iron. In: Proceedings of the 12th North American manufacturing research conference; 1984. p. 265–70.
[25] Chow CB, Liu YH, Miao HC, Lo ZP. Investigation on the cutting performance of silicon nitride ceramic tools. In: International conference manufacturing engineering; 1980. p. 71–4.
[26] Ezugwu EO, Machado AR. Face milling of aerospace materials. In: Proceedings of the 1st international conference on behaviour of materials in machining; 1988. p. 3.1–11.