Improvement of Surface Roughness by Particle Swarm Optimization in Hot Air Streaming Turning Process of Mild Steel

Md. Anayet U. Patwari, Mohammad Ahsan Habib, Md. Minhazul Islam, and Md. Firoz Mahmud
Department of Mechanical and Chemical Engineering, Islamic University of Technology, Dhaka, Bangladesh
Email: apatwari@iut-dhaka.edu , mahabib@iut-dhaka.edu, minhaz.6655@gmail.com, firozmahmud@iut-dhaka.edu

Abstract— **In machining operation, the quality of surface finish is an important concern for many finished work products. Thus, the choice of optimized cutting parameters like speed, feed and depth of cut is very important for controlling the required surface quality. The focus of present experimental study is to optimize the cutting parameters using the surface roughness as performance measure. The experimental result shows that the work piece surface roughness can be used effectively as a beacon to control the cutting performance. The modeling of the experimentally obtained data is being done using the regression analysis. Optimal cutting parameter for performance measure is obtained employing Particle Swarm Optimization (PSO) in order to get the minimum surface roughness and compared with the experimentally obtained data. The adequacy of the models of surface roughness has been established to achieve minimum surface roughness.**

Index Terms— **hot air, surface roughness, turning operation, optimization, convergence, particle swarm optimization**

I. Introduction

Surface roughness has acquired serious contemplation for many years devising a paramount design feature in many conditions such as parts subjected to fatigue loads, precision fits and aesthetic requirements. It imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning coupled with tolerances. A considerable number of studies have investigated the general effects of the speed, feed, and depth of cut on the surface roughness to improve the effectiveness of these turning processes and to quantify the effect of various parameters to surface quality. To gain a greater understanding of the turning process it is necessary to understand the impact of the each of the variables and the interactions between them. Finding all the variables impacting surface roughness in turning operations is unmanageable as it is costly and time consuming to perceive the effect on the output. To simplify the problem elimination or selecting specific variables that correspond to practical applications is a prime need. Now a day's in manufacturing industry, special attention is given to dimensional accuracy and surface finish. So measuring and characterizing the surface finish can be reified as the predictor of the machining performance [1]. Turning is the primary operation is most of the production process in the industry. The turning operation meets the critical feature that requires specific surface finish. The operators working on lathe use their own experience and machining guidelines to achieve the best desire surface finish. Due to inadequate knowledge and surrounding factor may cause high production costs and low quality. So, the proper selection of cutting tools and process parameters is very important in turning operation [2]. An experimental investigation was conducted to determine the effects of cutting conditions and tool geometry on the surface roughness in the finish hard turning of the bearing steel by Singh et.al. [3]. AKM Nurul Amin et. al [4] investigated the combined effects chip serration with systems components on machining responses. Analysis of surface roughness by turning process using Taguchi method was conducted by S. Thamizhmanii et.al. [5]. Patwari et al. introduced Investigation of surface parameters during hot air streaming turning process of mild steel [6]. An Experimental Investigation of Hot Machining with Induction to Improve Ti5553 Machinability was done by M. Baili et.al. [7]. Abou-El-Hossein et.al. discussed the development of the first and second order models for predicting the cutting force produced in end-milling using the response surface methodology to study the effect of cutting parameters on cutting force [8]. The predictive models produced values of the cutting force close to those readings recorded experimentally with a 95% confident interval. Jeang determined the optimal cutting parameters required to minimize the cutting time while maintaining an acceptable quality level [9]. The proposed expert system could able to recommend helix angle of the tool, milling orientation and also could predict tool life, surface roughness and cutting force for a high speed milling operation. Zain et.al. [10] applied Genetic Algorithm (GA) to find optimal cutting conditions for obtaining minimum surface roughness. The analysis of the study has proved that GA technique could able to perform better than experimental sample data, regression modeling and response surface methodology. Ahn et.al. proposed a methodology to predict the surface roughness

Manuscript received October 11, 2018; revised May 16, 2019.

doi: 10.18178/ijmerr.8.4.588-593

of layered manufacturing processed parts such as sphere model and teapot model [11]. Kalla et.al. studied the machining of carbon fiber reinforced polymers in a helical end mill and developed a methodology for predicting the cutting forces by transforming specific cutting energies from orthogonal to oblique cutting [12]. Predictions were in good agreement with the experimental data in unidirectional laminate but lesser agreement in multidirectional. Machining condition of turning operation by considering unit cost of production using dynamic programming technique and also investigated the influence of cutting parameters on surface roughness [13]. James Kennedy et al. developed PSO, which is a population based search procedure that could yield global optimum solution [14]. Tansel et al. represented the relationship between the cutting condition and machine related variables. Optimal operating conditions were also calculated to obtain the best possible compromise between roughness of machined surface and the duration [15]. Srinivas et.al. proposed particle swarm optimization for selecting optimized machining parameters in multi-pass turning operation for a component of continuous form[16].

To meet the required roughness specification, selection of appropriate values of machining parameter is very important. Several parameters such as cutting speed, feed rate, depth of cut, cutting force, tool wear, spindle speed (RPM), tool geometry, chip loads, chip formation, coolant etc. influence surface roughness. From these various factors some factors can be easily controlled. Among these factors, spindle speed (RPM), feed rate and depth of cut are considered as a process variable for this particular study. To determine the desirable cutting parameters value several experiment were conducted and to check the repeatability few experiments were also repeated. The appropriate cutting condition is very important for the manufacturing products & efficiency of the turning operation. In recent years, particle swarm optimization (PSO) is very popular as this is used in various engineering applications. The aim of the present investigation is to analyze optimal cutting parameters using Particle Swarm Optimization (PSO) in order to get the minimum surface roughness. From the experimental finding mathematical model has been developed and the developed model has been coupled with the PSO model for the prediction of minimum surface roughness. The predicted model has also been compared with the physical parameters to assess the accuracy of the models to achieve minimum surface roughness.

II. Experimental Details

The current Investigation has been done through the following steps

a) Checking and preparing the Centre Lathe ready for performing the machining operation.

b) Cutting ASTM A36 bars by power saw and performing initial turning operation in Lathe to get desired dimension (of diameter 32 mm and length 150mm) of the work pieces.

c) Performing hot air straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut.

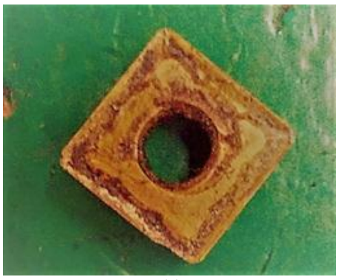
d) Measuring surface roughness and surface profile with the help of a portable stylus-type profilometer.

To provide hot air, a hot air gun was used which is able to generate hot air at temperature 31 ℃ to 205 ℃ in 120s. The hot air gun is able to apply hot air on the mild steel. Hot air velocity can also be changed to get the different temperature effects on machined surface. Fig. 1 shows the schematic diagram of the experimental setup.

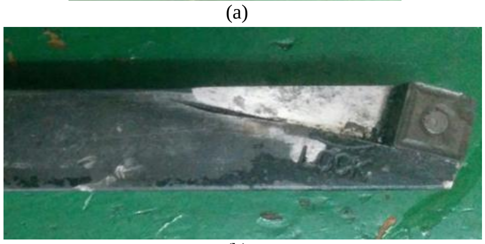
Figure 1. Experimental set up

During preheating the hot air gun was kept at an angle of 45^0 at a distance 2 inch from the work piece for the time of 1 minute and 40 seconds to achieve the required temperature. The mitutoyo SURFTEST SJ-210, a contact profilometer, was used in this study to measure the surface roughness of the machined surface.

In this study, the different process parameters have chosen based on literature review and considering the range of the machine. Three levels have been considered for spindle speed, feed and depth of cut. The different process parameters are shown in Table I. In this study a coated carbine insert has been used. The different experiment has been conducted as per design shown in Table II. Figure 2 shows the tool holder and insert photograph used in different experiments.



(a)



(b)

Figure 2. (a) Carbide coated insert (b) Tool holder

TABLE I. DIFFERENT LEVELS OF PARAMETERS

Variables		Values of different levels		
Designation	Description	Low	Medium	High
RPM	Spindle Speed	220	530	860
D.O.C	Depth of cut(mm)	0.5	1	1.5
FEED	Feed rate(mm/rev)	0.095	0.19	0.38

To find the optimum machining parameters and to get the minimum surface roughness using Particle Swarm Optimization (PSO) different experiment has been conducted and the results are illustrated in Table II. A number of 27 samples were taken during turning operation considering the speed, feed and depth of cut and their respective surface roughness. Furthermore, Surface roughness values from fitness value function have been presented in the table below.

TABLE II. EXPERIMENTAL VALUES

Experiment No.	Speed (RPM)	Depth of cut, D.O.C (mm)	FEED (mm /rev)	Surface Roughness Ra (µm) (Experimental)	Surface Roughness Ra (µm) (From Fitness Value Function)
01	860	1.5	0.38	6.42	5.345
02	860	1.5	0.19	1.78	2.349
03	860	1.5	0.095	1.13	1.036
04	860	1	0.38	6.16	5.766
05	860	1	0.19	1.46	2.443
06	860	1	0.095	1.07	0.969
07	860	0.5	0.38	6.10	5.974
08	860	0.5	0.19	1.82	2.349
09	860	0.5	0.095	1.03	0.691
10	530	1.5	0.38	6.06	7.383
11	530	1.5	0.19	4.35	4.480
12	530	1.5	0.095	4.47	3.225
13	530	1	0.38	5.23	7.478
14	530	1	0.19	5.93	4.254
15	530	1	0.095	2.91	2.827
16	530	0.5	0.38	8.53	7.383
17	530	0.5	0.19	3.69	3.806
18	530	0.5	0.095	2.31	2.216
19	220	1.5	0.38	8.64	8.524
20	220	1.5	0.19	5.55	5.766
21	220	1.5	0.095	4.06	4.504
22	220	1	0.38	10.53	8.313
23	220	1	0.19	5.78	5.182
24	220	1	0.095	2.79	3.806
25	220	0.5	0.38	6.64	7.886
26	220	0.5	0.19	3.94	4.427
27	220	0.5	0.095	2.77	2.883

Process Flowchart

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest. The particle swarm optimization algorithm has been arranged in a sequential manner to find out the global optimum solution. Fig. 3 shows the process flow chart of the developed PSO model.

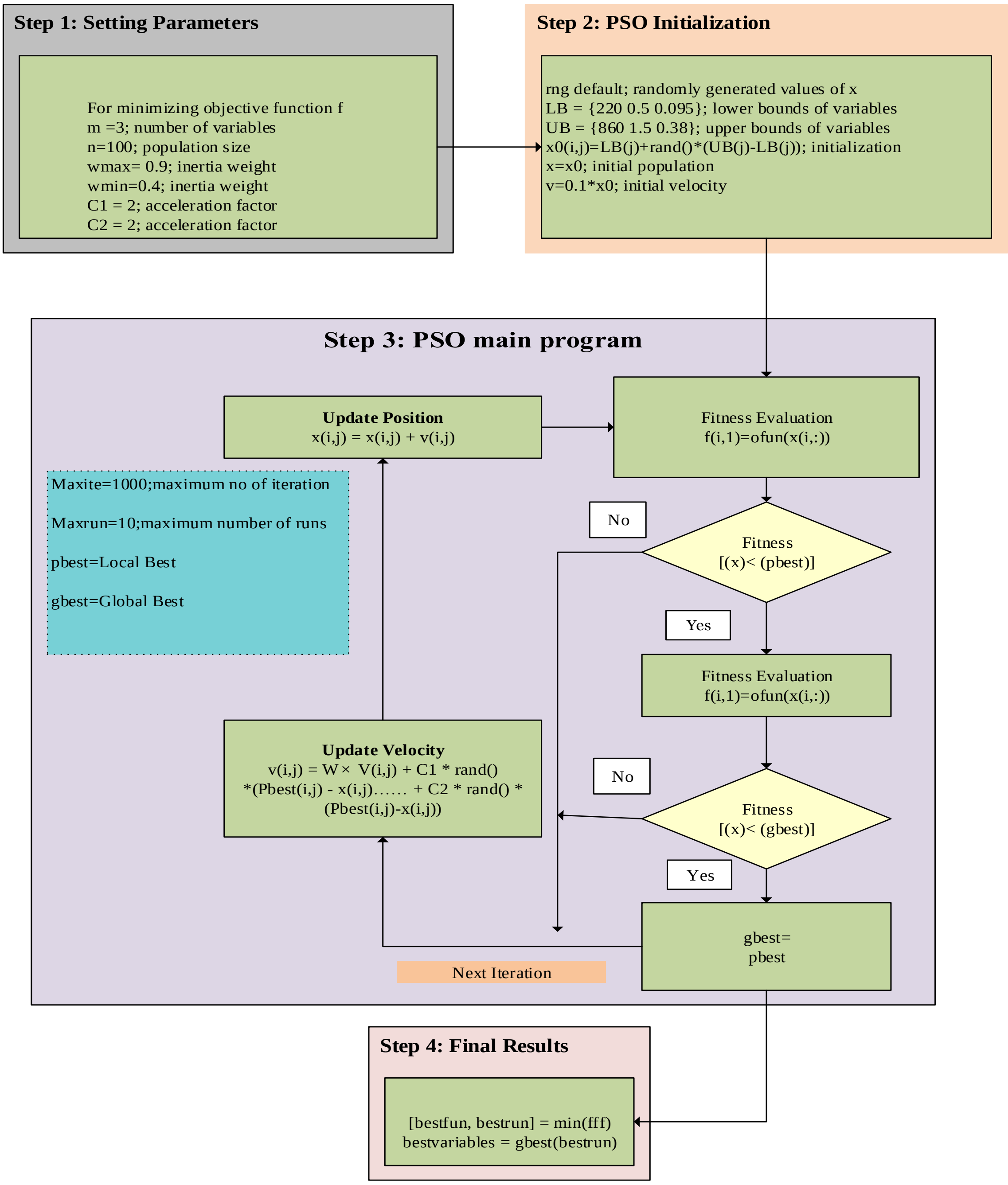


Figure 3. Particle swarm optimization algorithm

Formulation of Objective Function:

The absolute development of machining process planning is based on optimization of the economic criteria subjected to technical and managerial constraints which are the objectives of machining operations in terms of quality. Considering surface roughness minimization as the main manifestation the objective function formulated is given below

function f=ofun(x)

$$f = 0.001612x_1 + 3.24619x_2 + 15.68145x_3 - 0.0000039x_1^2 - 0.43104x_2^2 + 6.84355x_3^2 - 0.0019778x_1x_2 + 0.00158x_1x_3 - 3.4518x_2x_3$$

PSO Convergence Characteristics:

In relation to PSO the word convergence typically refers the convergence of the sequence of solutions (stability analysis, converging) in which all particles have converged to a point in the search-space, which may or may not be the optimum or Convergence to a local optimum where all personal bests p or alternatively, the swarm's best known position g, approaches a local optimum of the problem, regardless of how the swarm behaves. Convergence of the sequence of solutions has been investigated for PSO. These analyses have resulted in guidelines for selecting PSO parameters that are believed to cause convergence to a point and prevent divergence of the swarm's particles.

III. Results and Discussions

The aim of this work was to investigate the effects of the cutting parameters on the surface roughness during the hot air streaming turning process of ASTM A36 steel. Experimental results demonstrate that the rpm, depth of cut and feed rate are the main three controllable factors that influence the surface roughness in turning process. Relationship of surface roughness changing is established with cutting parameter changes.

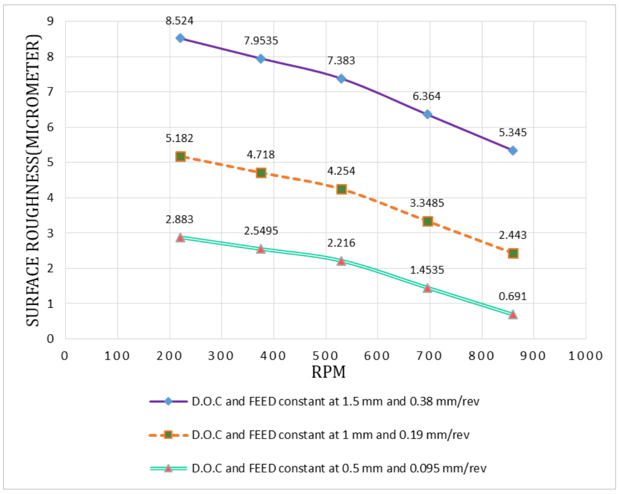


Figure 4. Effect of RPM on surface roughness

Firstly, the values of surface roughness have been plotted against rpm. With the lowering of rpm, the surface roughness value is lower. The lowering value of rpm together with low feed rate and depth of cut shows the best surface roughness result. Fig. 4 shows the effect of surface on surface roughness at different feed. It appears from the graph that with the increase of rpm the surface roughness decreases but the increase of feed the average surface roughness value increased.

Secondly, the values of surface roughness have been plotted against depth of cut with the feed and rpm as hown in Fig. 5. With the lowering of the depth of cut the surface roughness value is lower. The lowering value of depth of cut accompanied by high rpm and low feed shows the best surface roughness result.

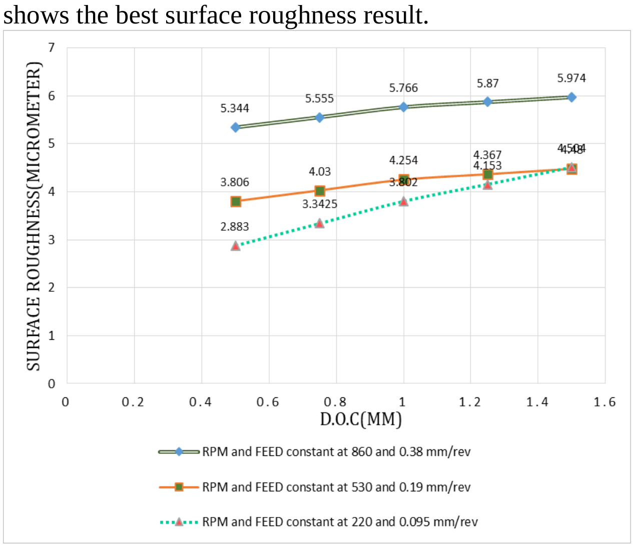


Figure 5. Effect of depth of cut on surface roughness

Thirdly, the values of surface roughness have been plotted against feed rate as shown in Fig. 6. With the lowering of the feed rate the surface roughness value is lower. The lowering value of feed rate with high rpm shows the best surface roughness result.

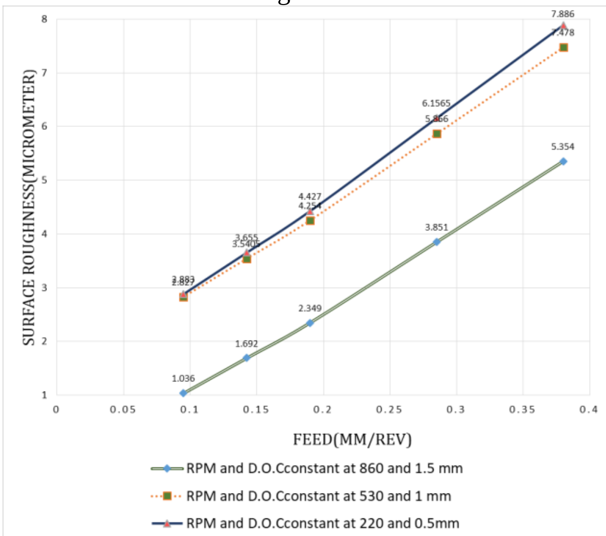


Figure 6. Effect of FEED on surface roughness

The value of the best variables using Particle Swarm Optimization has been obtained. In turning, use of greater rpm, low feed rate and low depth of cut are recommended to obtain better surface roughness for the specific test range. Hence the Particle Swarm Optimization method provides a simple, systematic and efficient methodology for the optimization of the cutting parameters.

IV. Conclusions

The modeling and the optimization of the experimentally obtained data were performed using the regression analysis which shows the corresponding values of objective function for corresponding rpm, feed and depth of cut and the results are as follows.

By optimizing of surface roughness:

Optimum revolution per minute = 860 rev/min

Optimum feed = 0.095 mm/rev

Optimum depth of cut = 0.50 mm

Minimized surface roughness =0.691 μm

The results of the modeling are in good agreement with the experimentally obtained data. In this paper a coupled algorithm has been applied for prediction of optimum surface roughness in hot air machining using PSO technique. This method may be used for finding the good quality surface profile in any machining process using hot air technique or any other techniques.

References

[1] N. S. K. Reddy and P. V. Rao, “Selection of optimum tool geometry and cutting conditions using a surface roughness prediction model for end milling,” *The International Journal of Advanced Manufacturing Technology*, vol. 26, no. 11-12, pp. 1202-1210, 2005.

[2] C. Y. Nian, W. H. Yang, and Y. S. Tarng, “Optimization of turning operations with multiple performance characteristics,” *Journal of Materials Processing Technology*, vol. 95. no. 1, pp. 90-96, 1999.

[3] D. Singh and P. V. Rao, “A surface roughness prediction model for hard turning process,” *The International Journal of Advanced Manufacturing Technology*, vol. 32, no. 11, pp. 1115-1124, 2007.

[4] AKM Nurul Amin, I. H. Jaffar, A. U. Patwari, W. W. D Zubaire, “Role of discrete nature of chip formation and natural vibrations of system components in chatter formation during metal cutting,” *IIUM Engineering Journal*, vol. 11, no. 1, 2010.

[5] S. Thamizhmanii, S. Saparudin, and S. Hasan, “Analyses of surface roughness by turning process using Taguchi method,” *Journal of Achievements in Materials and Manufacturing Engineering*, vol. 20, no. (1-2), pp. 503-506, 2007.

[6] A. U. Patwari, M. A. Habib, M. F. Mahmud, and M. M. Islam, “Investigation of surface parameters during hot air streaming turning process of mild steel,” in *Proc. AIP Conference Proceedings*, vol. 1851, no. 1, p. 020072, AIP Publishing, 2017, June.

[7] M. Baili, V. Wagner, G. Dessein, J. Sallaberry, and D. Lallement, “An experimental investigation of hot machining with induction to improve Ti-5553 machinability,” In *Applied Mechanics and Materials* vol. 62, pp. 67-76, Trans Tech Publications, 2011.

[8] K. A. Abou-El-Hossein, K. Kadirgama, M. Hamdi, K. Y. Benyounis, “Prediction of cutting force in end-milling operation of modified AISI P20 tool steel,” *Journal of Materials Processing Technology*, vol. 182, no. 1, pp. 241-247, 2007.

[9] A. Jeang, “Robust cutting parameters optimization for production time via computer experiment,” *Applied Mathematical Modelling*, vol. 35, no. 3, pp. 1354-1362, 2011.

[10] A. M. Zain, H. Haron, and S. Sharif, (“Application of GA to optimize cutting conditions for minimizing surface roughness in end milling machining process,” *Expert Systems with Applications*, vol. 37, no. 6, pp. 4650-4659, 2010.

[11] D. Ahn, H. Kim, and S. Lee, (“Surface roughness prediction using measured data and interpolation in layered manufacturing,” *Journal of materials processing technology*, vol. 209, no. 2, pp. 664-671, 2009.

[12] D. Kalla, J. Sheikh-Ahmad, and J. Twomey, (“Prediction of cutting forces in helical end milling fiber reinforced polymers,” International Journal of Machine Tools and Manufacture, vol. 50, no. 10, pp. 882-891, 2010.

[13] A. Manna, S. Salodkar, “Optimization of machiningconditions for effective turning of E0300 alloy steel,” *J Mater Process Technol*, vol. 203, pp. 147–153, 2008.

[14] J. J. Kennedy, R. Eberhart, “Particle swarm optimization,” *Proceed IEEE Int Conf Neural Networks,* vol. 4, pp. 1942–1948, 2000.

[15] I. N. Tansel, B. Ozcelik, W. Y. Bao, P. Chen, D. Rincon, S. Y. Yang, A. Yenilmez, “Selection of optimal cutting conditions by using GONNS,” *Int J Mach Tools Manuf*, vol. 46, pp. 26–35, 2006.

[16] J. Srinivas, R. Giri, S. H. Yang, “Optimization of multi-pass turning using particle swarm intelligence,” *Int J Adv Manuf Technol,* vol. 40, pp. 56–66, 2009.

Md. Anayet U. Patwari is working as Professor in the Department of Mechanical and Chemical Engineering of Islamic University of Technology, Dhaka, Bangladesh. He has wide experience in manufacturing and mechanical engineering field. He published more than 180 research papers in the field of smart machining, chatter in machining, simulation and optimization etc. in different international journals and proceedings.

Mohammad Ahsan Habib is working as an Assistant Professor in the Department of Mechanical and Chemical Engineering of Islamic University of Technology, Dhaka, Bangladesh. He received his Ph. D. from National University of Singapore (NUS) in Engineering. His research interest in Conventional and Non-conventional Manufacturing Technique; Computer-aided Design, Engineering & Manufacturing (CAD, CAE, CAM), Automobile and Mechatronics.

Md. Minhazul Islam received the B. Sc. Eng. (Mechanical) Degree from Department of Mechanical and Chemical Engineering, Islamic University of Technology, Dhaka, Bangladesh, in November 2017. His research interests are Automobile Engineering, Material science, Manufacturing Process, Machine Design, Fluid Mechanics & Control and Automation.

Md. Firoz Mahmud received the B. Sc. Engg. (Mechanical) from Department of Mechanical and Chemical Engineering, Islamic University of Technology, Dhaka, Bangladesh, in November 2017. His research interests are in Machining, Manufacturing Process, Fluid Mechanics, Renewable Energy, Heat Transfer and Biomedical Engineering.