EGTRIB Journal

JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 17, No. 1, January 2020, pp. 53 - 61 **ISSN 2090 - 5882**
(Received December 22. 2019, Accepted in final form December 29. 2019) **www.egtribjournal.com**

OPTIMIZATION OF ROUNDNESS ERROR IN HARD TURNING OF AISI H13 TOOL STEEL

Ahmed A. Elsadek, Ahmed M. Gaafer and S.S. Mohamed

Department of Mechanical Engineering, Faculty of Engineering at Shoubra,
Benha University, Cairo, Egypt.

ABSTRACT
In the current investigation, a novel optimization algorithm, named the Duelist algorithm (DA), is employed for optimizing the roundness error by the proper selection of the input machining parameters in hard turning of AISI H13 steel. Furthermore, the effect of workpiece hardness in addition to cutting parameters such as depth of cut, feed and depth of cut on the roundness error in hard turning will be discussed. The outcomes showed that the feed rate was the most significant factor influencing the roundness error. Besides, it was reported that the hardness of the workpiece reduced the roundness error although it is a statistically insignificant parameter. Finally, the DA proved its robustness in optimizing the machining problem. Experimental confirmation test were applied to prove the results of the optimization algorithm.

KEYWORDS
Hard turning, Optimization, Duelist Algorithm, roundness error.

INTRODUCTION
Hard turning is becoming more popular as a pre-grinding process, as a result of its lower costs compared with grinding because of employing grinding- wheels which are costlier than hard turning tooling, which is performed on the ordinary turning lathes, [1]. The best advantage of hard turning is the reduced machining time as well as the improved quality of products and few different advantages are elaborated within the literature, [2 - 7]. An important application for the hard turning is dies manufacturing, in which complicated geometries, high hardness materials and the short lead time are among the challenges that faces engineers.

In the meantime, quality prerequisites become increasingly more significant because of the strengthened industrial competitions and product quality realization. Thus the main consideration in metal-cutting is improving the overall performance of the cutting process. This work investigates the impact of workpiece hardness and cutting parameters

such as cutting speed, feed and depth of cut on the roundness error. Besides, it discusses optimizing the input parameters in hard turning of tool steel AISI-H13 - for minimizing of the roundness error (also known as out-of-roundness or circularity) in hard turning by DA. As optimizing the cutting processes is an important issue, thus in the recent years it has been the target of research, [8 - 14]. It is value to note that despite a huge number of researches were concerned with studying the effect of various machining parameters on cutting force, cutting power, tool wear and surface roughness. Only few researches were concerned with studying the roundness error and particularly the effect of workpiece hardness on it is a factor of high importance for rotating parts where a large roundness error might results in vibration and heat.

EXPERIMENTAL MATERIALS

Round bars of diameter 35 mm and 100 mm length of AISI-H13 tool steel and of primary hardness 207 HB with chemical composition shown in Table. 1, hardened to 45±1, 50±1 and 55±1 HRC were utilized as workpieces. A mixed ceramic insert was mounted on a negative rake angled shank. Dry turning tests were performed on a conventional lathe. A three jaw chuck and tailstock where employed in workpiece clamping on the lathe.

Table 1. Chemical Composition of AISI-H13 workpieces

element	C	Mo	V	Mn	Cr	Si	P	S
%	0.390	1.250	0.920	0.48	4.88	1.09	0.012	0.002

RESULTS AND DISCUSSION

Response surface central composite design (CCD) was employed for experimental design. The factors employed were Speeds of 100, 125 and 150 m/min, feeds rates of 0.05, 0.1, 0.15 mm/rev, depth of cuts of 0.05, 0.09, 0.13 mm along with workpiece hardness values of 45 ± 1, 50 ± 1 and 55 ± 1 HRC. The experiments were done and the results were reported. The investigational plans were established for the setting up of linear models for roundness error. Table 2 reveals the lack of fit check for roundness error to determine if the established model passed the lack of fit tests. Analysis of variance (ANOVA) was employed in checking the adequacy of the proposed model revealed in Table 3.

Table 2 lack of fit check for roundness error.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Linear	176.26	20	8.81	1.33	0.4064	Suggested
2FI	103.61	14	7.40	1.11	0.4904	
Quadratic	63.18	10	6.32	0.9517	0.5594	
Cubic	14.05	2	7.02	1.06	0.4138	Aliased
Pure Error	33.19	5	6.64			

The linear-model for roundness has an F-Value of 14.16, which means that there is 40.64 % casual, that this large "lack of fit F-value" might have happened due to unrequired noise. The table also reveals that the "Lack of fit" of the prosed model is insignificant, which is desirable since it is required for the model to fit. In this established roundness model the terms feed "B" is the statistically significant term and the most influencing factor similar findings were obtained, [15, 16]. The feed "B" with a contribution percent of 59.774% comes first as the most important parameter on dealing with roundness error followed by the workpiece hardness "D" followed by the depth of cut "C" each of the two responses have a contribution percent less than 5% and finally the cutting speed "A" with a contribution percent less than 0.5%. Therefore, the obtained results possesses a good agreement with the previous researcher's works.

Table 1 ANOVA results for roundness error

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	474.58	4	118.65	14.16	< 0.0001	significant
A-Speed	2.84	1	2.84	0.3390	0.5656	
B-Feed	408.88	1	408.88	48.80	< 0.0001	significant
C-Depth of Cut	31.15	1	31.15	3.72	0.0653	
D-Hardness	31.71	1	31.71	3.78	0.0631	
Residual	209.45	25	8.38			
Lack of Fit	176.26	20	8.81	1.33	0.4064	not significant
Pure Error	33.19	5	6.64			
Cor Total	684.04	29				

This linear model generated by the design can be represented by the following equation:

$$Yu = \beta o + \sum_{i=1}^{n} \beta i \, xi + e \qquad (1)$$

Where Yu is the required response (roundness error), β_o, β_1... β_i are the regression coefficients, 'x' is the independent variables and 'e' is the error.
The above mentioned equation representing the roundness linear-model in terms of in the actual factors can be re-written in the form of Equation 2:

$$\text{Roundness "O"} = 14.94956 + 0.0158889 * \text{Speed} + 95.32222 * \text{Feed} + 32.88889 * \text{Depth of Cut} - 0.2654444 * \text{Hardness} \qquad (2)$$

Examining of the residuals is necessary for checking the established model for adequacy. This analysis of residuals is necessary for confirming that assumptions for ANOVA are being met. Figure 1, reveals the residuals against run test. The figure shows that the value points are randomly distributed. The value points do not take a definite shape which is desirable. Furthermore, Figure 2 shows the predicted response vs the actual values in which the points of the predicted response and the actual value points are randomly distributed along a 45° line. This also indicates that the established model is adequate and there is no reason to suspicious any constant variance, [17]. Then the suggested model is satisfactory and can be utilized as it comply with previous works. Figure 3 (a-b) shows

the 3D response surfaces curves for the roundness error, it is clear from the figures that the lowest roundness value was obtained at the lowest value of feed along with the highest hardness value. Also the cutting speed and the depth of cut are the least influencing factors. This agree with the later discussion. The reason that high workpiece hardness improved roundness error can be attributed to the increase in shear angle with increasing hardness, [17], which results in reduction of shear plane and consequently reduce the separation force leading to reduction of workpiece deflection which causes the geometrical errors.

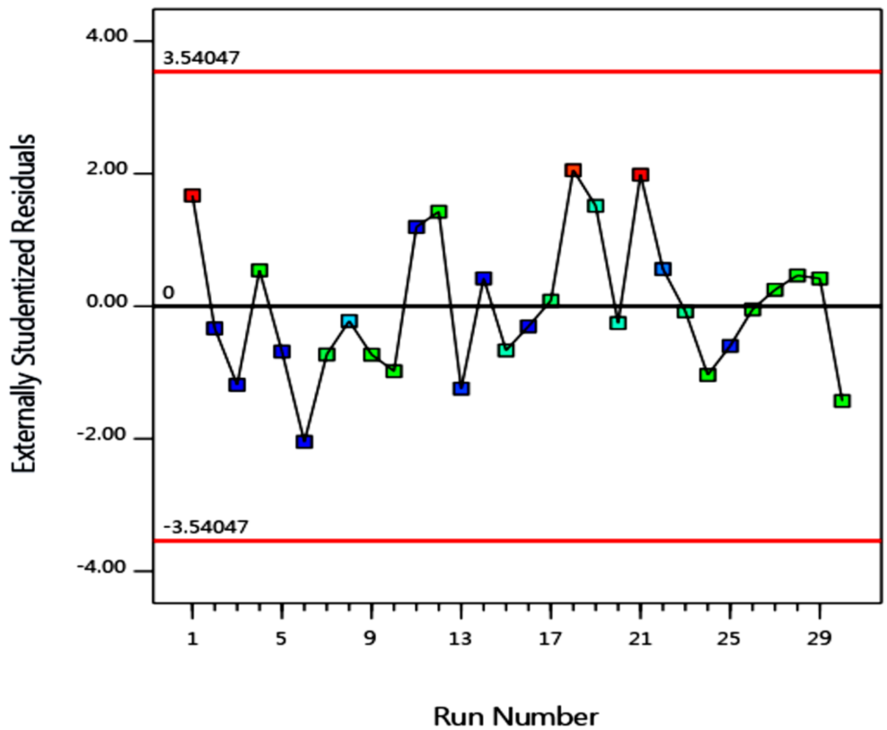


Fig. 1 Residuals against run tests for roundness error.

A fundamental goal of any experimental design including machining is acquiring the optimal values of inputs at least costs to improve the efficiency of procedure. Duelist Algorithm (DA) is a new evolutionary optimization algorithm proposed, [18], inspired by human fighting competitions. It is a novel algorithm based on the genetic algorithm and inspired by human fighting and learning abilities. In the present work, equation (2) will be employed as the objective function for minimizing the roundness error in which the target was to find the global minima employing the new DA in search, employing the limits of various input variables as boundaries. To test the results of DA well-known genetic algorithm (GA) was employed in search following the same procedure.

The objective of the present work is employing equation (2) for minimizing the roundness error in hard turning of H13 tool steel.

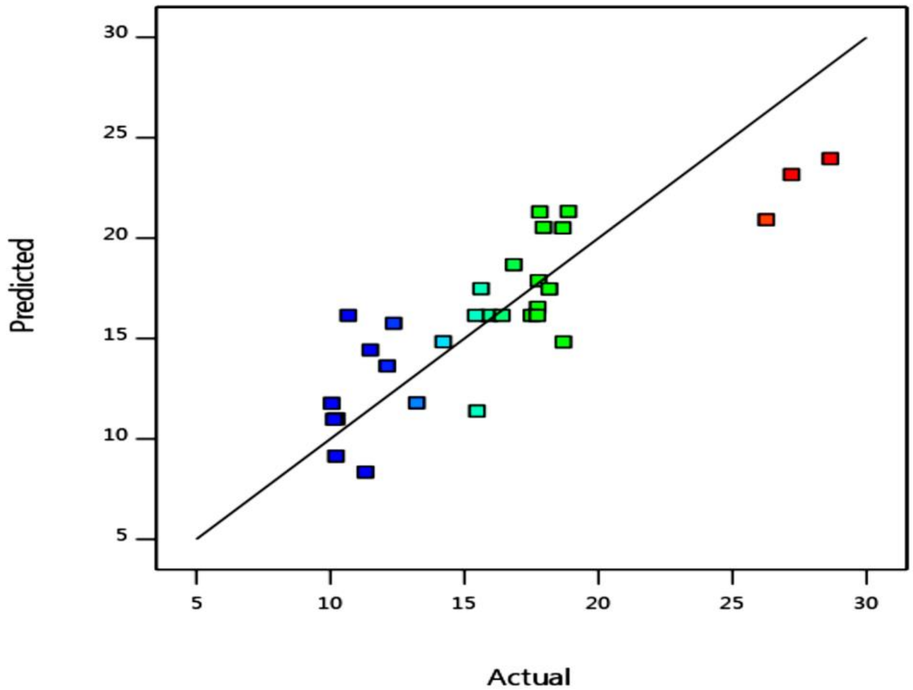
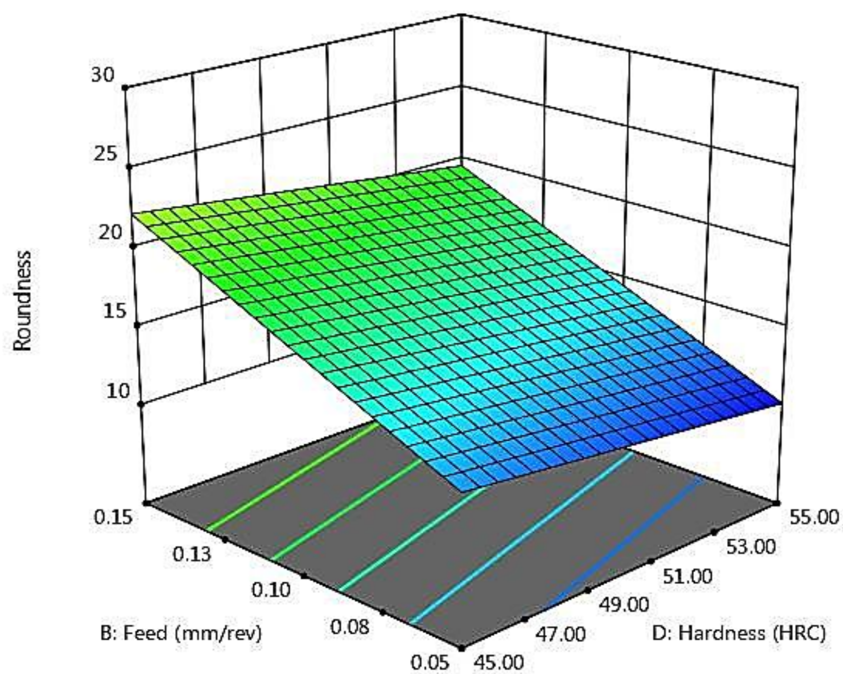


Fig. 2 Predicted response vs the actual values for roundness error.



h = 50 HRC & f = 0.1 mm/rev

v = 125 m/min & d = 0.09 mm

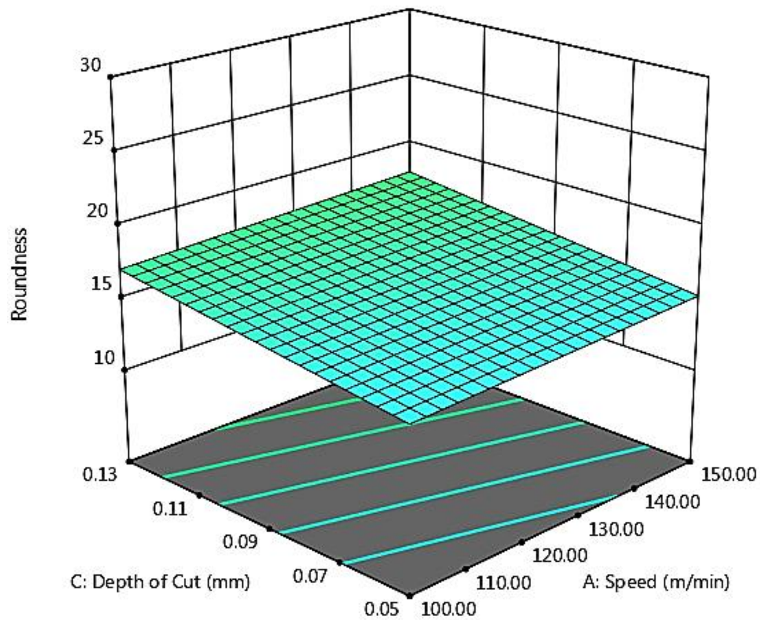


Fig. 3 3D Response surfaces curve for the roundness error.

Roundness Error "O" = Minimize[Y (v, f, d, h)]. Subjected to:

$$\begin{cases} 100 \le v \le 150 \\ 0.05 \le f \le 0.15 \\ 0.05 \le d \le 0.13 \\ 45 \le h \le 55 \end{cases}$$

In this optimization scheme, the number of duelist will be set to n = 40, and the total number of iterations shall be set to 500. After running the script utilizing the roundness error equation (2) the optimum value for roundness error was found to be O = 8.3791 µm and the corresponding best cutting parameters were found to be v = 100 m/min, f = 0.05 mm/rev, d = 0.05 mm and h = 55 HRC after 165 iterations. Applying the "GA" using the mentioned above equation as objective function, the same parameter boundaries and a population of size 40. The obtained value of roundness was O = 8.3497 µm at a total number of iterations of 254. Figure 4 (a-b) reveals the convergence plot for DA and GA respectively.

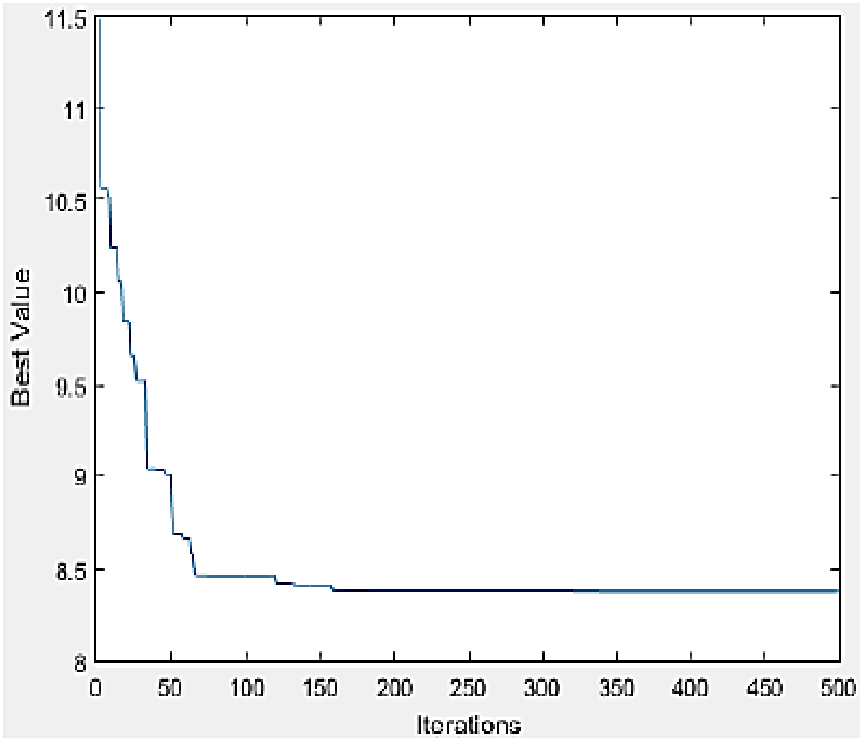


Fig. 4 (a) The convergence plot for DA.

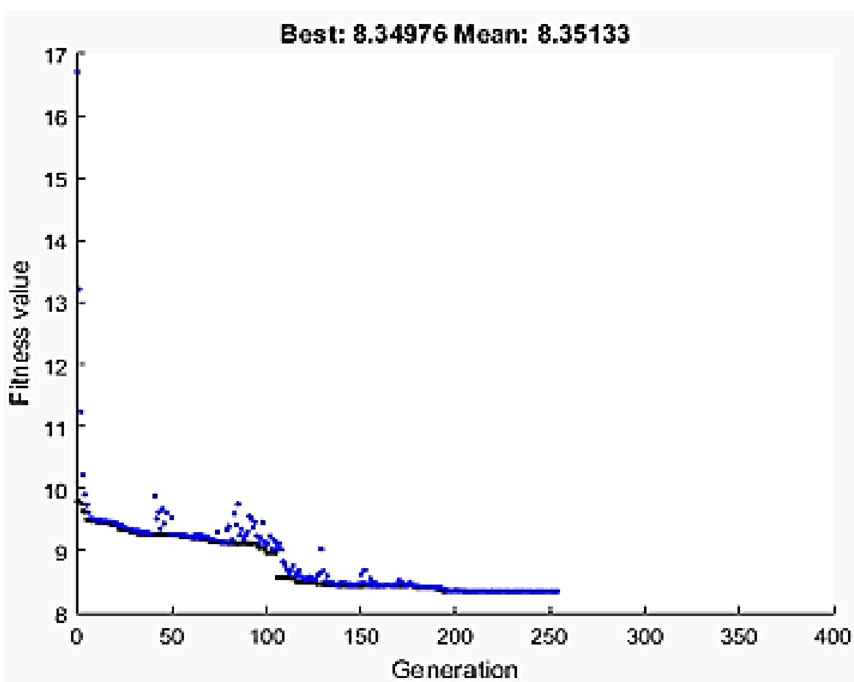


Fig. 4 (b) The convergence plot for GA.

Thus DA demonstrated its efficiency in terms of quicker convergence rate as compared to GA. Though GA was better in getting the global minimum of the optimization problem. Finally, the optimum values of the input variables were utilized for confirming the results experimentally where the corresponding values of roundness error was obtained and the error percent was calculated. The error resulted between the predicted values and the average value for five tests (8.783 µm) was about 4.6% for DA and 4.9% below 5% indicating the accuracy of results for both algorithms.

CONCLUSIONS

This research aims to utilize a new optimization algorithm that is the Duelist algorithm (DA) in solving the hard turning problem. It also highlights the influence of workpiece hardness in addition to the speed, feed and depth of cut on the roundness error in hard turning. Response surface methodology (RSM) was employed in designing the experimental runs, then "hard-turning" experiments were performed on hardened AISI-H13-steel using mixed ceramic inserts, then the outcomes were reported. "Linear model" was proposed based on the outcome data for roundness error. A mathematical model was established for representing the relation among various input parameters. Analysis of variance was employed for model testing. DA was utilized for process optimization and GA was utilized for testing the results obtained by DA and the below can be decided as follows:

1. Response surface plot shows the effect of input parameters on the values of roundness error. Where the feed rate possess the major effect on roundness error values. Also, feed rate negatively affects the While other factors are statistically insignificant.
2. Although hardness effect is statistically not significant on the roundness error, yet the experimental results showed an improve in the value of roundness on increasing the workpiece hardness and this is due to increasing the shear angle as explained before.
3. The least roundness error can be obtained at the least values of feed, speed and depth of cut.
4. Though GA obtained the global minimum of the optimization problem, yet DA showed a quicker convergence rate in obtaining the best solution.
5. Confirmation tests were done utilizing optimal input parameters obtained using DA and GA. An error less than 5% obtained in both cases with a slight difference indicating the accuracy of results. This difference because of slight differences in the value of the best point obtained by both algorithms.

REFERENCES

1. Hard Turning and the Machine Tool, Soroka DP, Hardinge Inc. One Hardinge Dr.Elmira, NY 14902.
2. Huddle D., "New hard turning tools and techniques offer a cost-effective alternative to grinding". Tooling and Production Magazine Vol. 80, pp. 96–103, (2001).
3. Narutaki N., Yamane Y., "Tool wear and cutting temperature of CBN tools in machining of hardened steels", Annals of the CIRP 28/1, pp. 23–28, (1979).
4. Hodgson T., Trendler P. H. H., Michelletti G.F., "Turning hardened tool steels with

Cubic Boron Nitride inserts", Annals of the CIRP 30/1, 1981, pp. 63–66, (1981).
5. Chryssolouris G., "Turning of hardened steels using CBN tools, Journal of Applied Metal Working", 2, pp. 100–106, (1982).
6. Koenig W. A., Komanduri R., Toenshoff H. K., Ackeshott G., "Machining of hard metals, Annals of the CIRP 33/2", pp. 417–427, (1984).
7. Koenig W., Klinger M., "Machining hard materials with geometrically defined cutting edges", Annals of the CIRP 39/1, pp. 61–64, (1990).
8. Silambarasan S. and Prabhakaran G., "Optimization of Process Parameters of Wire EDM Using Genetic Algorithm", International Journal of Mechanical and Production Engineering Research and Development, Vol. 8, pp. 426-430, (2018).
9. Elsadek; A. A., Gaafer A. M., Lashin M. A., "Prediction of Roughness and Tool Wear in Turning of Metal Matrix Nanocomposites", J. Eng. App. Sci., Vol. 64, pp. 387-408, (2017).
10. Sathiya N., Baskar N., Ganesan M., "Multi Objective Optimization of machining parameters for Hard Turning OHNS/AISI H13 material, Using Genetic Algorithm", Materials and Manufacturing Processes, Vol. 5, pp. 6897-6905, (2018).
11. Sahu N. K., Andhare A. B., " Multi objective optimization for improving machinability of Ti-6Al-4V using RSM and advanced algorithms", Journal of Computational Design and Engineering, Vol. 6, pp. 1-12, (2019).
12. Widhiarso W., Rosyidi T., "Multi objective optimization model for minimizing production cost and environmental impact in CNC turning process" AIP Conference Proceedings, Vol. 1931, pp. 1-7, (2018).
13. Mia M., Królczyk G., Maruda R. and Wojciechowski S., "Intelligent Optimization of Hard-Turning Parameters Using Evolutionary Algorithms for Smart Manufacturing", Materials, Vol. 12, pp. 1-12, (2019).
14. Zhang W., Zhang L., Wang S., Ren B., Meng S., " Optimization of machining parameters of 2.25Cr1Mo0.25V steel based on response surface method and genetic algorithm. International Journal on Interactive Design and Manufacturing (IJIDeM). Vol. 13, pp. 809–819, (2019).
15. Rafai N. H., Islam M. N., " An Investigation into Dimensional Accuracy And Surface Finish Achievable In Dry Turning" Machining Science and Technology: An International Journal. Vol. 13:4, p. 571-589, (2009).
16. Bonhin E. P., Müzel D. S., De Souza J. V. C., Alves M. C., Ribeiro M. V., "Effect of machining parameters on turning of VAT32® superalloy with ceramic tool", Mater. Manuf. Process., Vol. 34, pp. 1–7, (2019).
17. Davim J. P., "Design of Experiments in Production Engineering", ISSN 2365-0450. (2015)
18. Wu D. W., Matsumoto Y., " The effect of hardness on residual stresses in orthogonal machining of AISI 4340 steel", Transactions of the ASME, Journal of Engineering for Industry. Vol. 112, pp. 245-252, (1990).
19. Biyanto T. R., Fibrianto H. Y., Nugroho G., Hatta A. M., Listijorini E., Budiati T., Huda., "Duelist algorithm: an algorithm inspired by how duelist improve their capabilities", in a duel. In: International conference in swarm intelligence. Springer, pp. 39–47, June (2016).