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A Closed Form Equation Obtained By Artificial Bee Colony For The Surface Roughness Of Aisi 1050 Steel

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Abstract

In this study, a new and simple formulation achieved using the artificial bee colony (ABC) that recently developed as an artificial intelligence optimization algorithm has been proposed in computing the surface roughness of the AISI 1050 steel. The steel exhibiting a good performance with respect to the mechanical strength is one of the widely–used carbon steels in the manufacturing process. Twenty experiments consisting of the various cutting parameters namely the cutting speed, rate of feed and depth of cut were performed in terms of the surface roughness with the help of a CNC horizontal machining center. The surface roughness formulation was constructed and then the unknown coefficients belonging to the formulation were optimally calculated by using ABC algorithm. The results obtained by using the presented formula were compaired with those of the method previously reported in the literature. The parametric studies are also carried out to evaluate the individual effect of the cutting speed, depth of cut and feed rate on the surface roughness of the AISI 1050 steel. The advantage of the proposed formulation is that it does not require any sophisticated mathematical computations and one can easily make an assessment the surface roughness according to cutting parameters. Further, it provides the obtaining of most accurate values in the surface roughness calculation of AISI 1050.

***Keywords**: Surface roughness; CNC milling; Artificial bee colony; AISI 1050 steel.*

1. Introduction

The medium carbon steels are one of the widely used alloy steels in the manufacturing industry due to their highly susceptible to heat operation. Further, the strengths of medium carbon steel are better than those of low carbon steels and the ductility of medium carbon steel is close to the low carbon steel. Due to these advantages, medium carbon steels may be preferred in the manufacturing industry [1].

In the manufacturing industry, the surface finish is of vital importance for quality characteristics of the product like the performance characteristic of mechanical parts and the cost of production. Recently, the modern industry is making an effort to produce high quality product in a very short time with less operator intervention by using new technologies developed in the computer science, computer numerical control (CNC) and flexible manufacturing systems [2, 3]. In order to provide a better finished surface and quality products, the several techniques are adopted in the manufacturing industries [2–4]. The common criteria for surface quality is the surface roughness. The low surface roughness values increase the fatigue life of machine part [2, 4–7]. The form of surface roughness can be affected from many factors as workpiece material, tool variables and machining parameters [2, 4, 5]. While cutting of the parameters consist the depth of cut, the rate of feed and cutting speed, the tool variables contain the tool material, tool vibration, rake and shear angle, cutting edge geometry and nose radius. Besides, the workpiece variable covers the machined material hardness and other mechanical attributes [2, 3].

The control of all the machining parameters like the surface roughness control and particular manufacturing processes is very difficult for users. The cutting parameters are usually chosen based on experience or it can be

determined by use of the manufacturer's user manuals [2, 3].
The several techniques based on statistical regression as neural network methods were used to obtained a relationship between the cutting performance and chosen cutting parameters [2, 3]. In the study presented by in [2], an optimization strategy for the CNC pocket milling process based on regression analysis including differential evolution algorithm was improved. In the wet cutting circumstances utilizing of the machining variables like spindle speed, feed rate, depth of cut and step over. Using a bisection method, Beak et al. chosen the optimal feed rate [8]. A numerical model by Franko et al. [9] was proposed for estimating the surface profile and surface roughness in the face milling with the round insert cutting tools. Lou and Chen [10], a new method for prediction of the systems was developed to predict surface roughness. An artificial neural network model approach performing the estimation of the surface roughness in CNC face milling was proposed by Benardos and Vosniakosa [11]. In a study by Zou et al., a technique based on a modified differential evolution algorithm was suggested to solve unconstrained optimization problems [12]. As mentioned above, the presented techniques for the prediction of the surface roughness or the surface profile is based on the consecutive mathematical formulas derived by using the complicated functions. Additionally, the applicability of proposed models based on artificial neural network is difficult in the practice. Therefore, the determination of surface roughness takes a lot of time and it requires experience of mathematics. In this study, to cope with the above problems, a simple and novel closed form expression based on the cutting parameters like cutting speed, rate of feed and depth of cut has been proposed by utilizing the ABC algorithm in the computing accurate surface roughness values for the AISI 1050 medium carbon steel plate.

2. Artificial bee colony (*ABC*) algorithm

The artificial bee colony (ABC) algorithm [13–21] is a swarm–based algorithm developed by using the motivation foraging behavior of the honey bees for determining close to the ideal solutions of the hard problems in the optimization processes. The swarm in the ABC algorithm consists of three groups like the onlooker, the employed and the scout bees. The honey bees fly to determine the optimal solution in a multidimensional search space. The employed bees are appointed to nectar resources taken advantages of its experiences. The onlooker bees determine the nectar resource position depending on the observing of the employed bees dancing in the hive and adjust their positions. In order to assign new food sources instead of the consumed food source, the scout bees perform a random search in the search space. Firstly, the colony divides two parts like the employed and onlooker bees. The possible solution points representing the number of food sources around hive are equal to that of the employed bees. In the following stage, the employed and onlooker bees exploit the food sources. If a nectar source is exhausted by an employed bee, this employed bee becomes a scout bee to find a new nectar source again [22].
The ABC algorithm pseudocode is illustrated below:

Initialization step:
Produce the population of the initial x_i=1, 2, …, SN
Calculate and judge the fitness (f_i) of the honey bee population
Cycle=1
Repeat
Employed bee step:
Generate new point of the solution
Compute and evaluate the fitness value of the f_i
Perform the greedy selection process
Compute the probability values (p_i) for the possible solution x_i
Onlooker bee step:
Choose a solution x_i according as p_i probability value
Generate new point of the solution
Compute and evaluate the fitness value of the f_i
Perform the greedy selection process
Scout bee step:
if an employed bee abandons from a nectar resource that is represented the possible solution, a new solution is determined by scout bee at random.
Save in memory the best solution determined so far
Cycle=Cycle+1
Until Cycle= Maximum Cycle Number (*MCN)*

The flow chart for the ABC algorithm is shown in Fig. 1. At the initial step, the values of possible solution points regarding the food source location randomly generate between two specified limitation values. The fitness (*quality*) of the produced values regarding to the quantities of the food is computed to judge the profitability in the first step.

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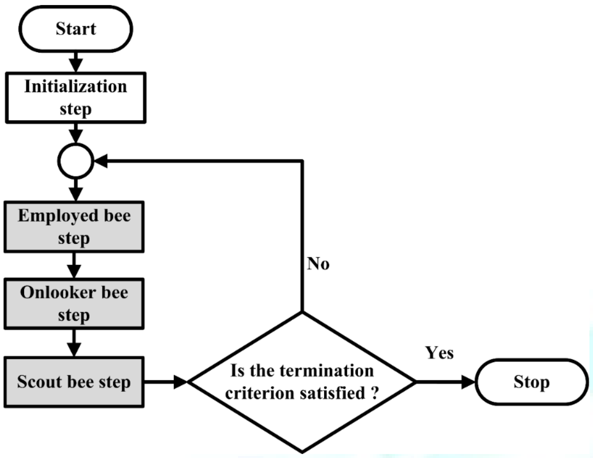


Fig. 1 The flow chart of the ABC algorithm

In the onlooker bees step, the possibility of the determined solution values for the problem is calculated and the best search new solutions in the environment of the points having high possibility values. In the scout bees step, if a determined solution point does not enhance after a specified number of trial limits, a new solution point is randomly identified as same the first step. Lastly, the detected best solution point of the problem is saved in memory and this process consecutively continues as much as the identified MCN [15].

3. The derivation of the surface roughness expression for AISI 1050 steel

In order to yield the expression of surface roughness (RaE), the experimental results given in [2] have been used for 20 samples having the surface roughness in the range of 0.95–6.55 μm. Firstly the parameters like the cutting speed v (rpm), rate of feed f (mm × min-1), depth of cut d (mm) have different values. In [2], the experiments of the pocket milling have been conducted on a FANUC CTEK CNC horizontal machining center using an end mill cutting tools made of 8 mm high speed steel (HSS) for the pocket milling of AISI 1050 medium carbon steel plate. The carbon steel plate used in this work has the dimensions of 472 × 184 × 40 mm3. The pockets were machined under constant step over value having the half of the tool diameter (4 mm). The forty pockets have been machined on the steel plate considering to recommended depth of cut given in design matrix and each pocket has the dimensions of 30 × 30 mm2. The properties of workpiece material utilized in the present study are listed in Table 1 [2].

Table 1: The chemical and mechanical properties of workpiece material of AISI 1050 [2].

Chemical Composition (*wt. -%*)	C	P	S	Mn	Cr	Si
	0.47	0.04	0.04	0.80	0.11	0.10

Mechanical Properties	Yield strength (*MPa*)	Tensile Strength (*MPa*)	Elongation (*%*)	Brinell Hardness (*HB*)
	580	690	15	197

Table 2: The experimental results for the surface roughness of AISI 1050 [2].

Case Number	Cutting Parameters			*RaE*
	Cutting speed *v (rpm)*	Feed rate *f (mm/min)*	Depth of cut *d (mm)*	*(μm)*
1	1650.00	450.00	2.00	2.33
2	2325.00	625.00	2.75	4.59
3	975.00	275.00	2.75	4.61
4	2785.21	450.00	2.00	2.31
5	1650.00	450.00	2.00	2.33
6	2325.00	625.00	1.25	1.24
7	1650.00	744.31	2.00	2.35
8	1650.00	450.00	2.00	2.33
9	1650.00	450.00	0.74	0.95
10	1650.00	450.00	2.00	2.30
11	1650.00	450.00	2.00	2.32
12	1650.00	450.00	3.26	6.55
13	2325.00	275.00	1.25	1.02
14	1650.00	155.69	2.00	2.09
15	514.79	450.00	2.00	2.88
16	975.00	275.00	1.25	1.28
17	2325.00	275.00	2.75	4.42
18	975.00	625.00	1.25	1.16
19	975.00	625.00	2.75	4.21
20	1650.00	450.00	2.00	2.33

In order to construct the best formulation structure which is proper with the experimental parameters for the related to surface roughness, the different formulation structures of the surface roughness formulas consisting of the unknown coefficients (ai) together with the experimental parameters (v, f and d) were constructed. The following average percentage error (APE) as objective function is used in the ABC method to be minimized.

$$TPE = \sum_{k=1}^{CN}\left[100\times\left|\frac{RaE_{exp_k}-RaE_{cal_k}}{RaE_{exp_k}}\right|\right] \quad (1)$$

In the above equation, RaE_{exp} and RaE_{cal} are the experimental and calculated surface roughness values, respectively. The values of ABC algorithm optimization parameters for this work are set as given in Table 3.

Table 3: The optimization parameters of the ABC algorithm used in this study.

ABC algorithm parameters	Assigned values

Number of dimensions (*D*)	5
Population size (*NP*)	60

A sequence of trials was performed to yield a surface roughness and the following equation which gives the satisfactory results is then determined.

$$RaE_{cal} = a_1 + \frac{a_2}{f} + a_3.d + \frac{a_4}{v} + d^{a_5} \quad (2)$$

The unknown coefficients in the surface roughness expression have been then determined as optimally and these coefficients are tabulated in Table 4.

Table 4: Coefficient values for the surface roughness expression of AISI 1050 steel determined by the ABC algorithm.

Index (i)	1	2	3	4	5
a_i	1.422	-35.670	-1.512	281.245	1.940

4. Numerical results and discussion

The obtained experimental and calculated values of RaE for 20 experiments are presented in Table 5. According to the calculations with formula obtained by ABC algorithm, the APE between the experimental RaE and calculated RaE was achieved as 2.95%. The calculated surface roughness results from the achieved expression with the ABC algorithm and those of the experimental values for 20 samples are plotted in Fig. 2. This good agreement between the experimental and calculated results supports the accuracy of the novel surface roughness formula. Furthermore, the fit of the proposed surface roughness expression was measured by a correlation coefficient (R2) and it was calculated with a high value as 0.993 in terms of the coefficient of determine the close between experimental RaE and calculated RaE. In order to verify the validity of the proposed expression, the surface roughness results calculated in this study were also compared with those of a suggestion reported elsewhere [2] over calculated results of AISI 1050 steel published earlier in the literature. These comparative results and corresponding percentage errors are given in Table 5.

Table 5: The comparative results for the *RaE* of AISI 1050 steel.

Case Number	Surface Roughness *RaE (µm)* Experimental [2]	Calculated This study	Calculated [2]	Error *(%)* This study	Error *(%)* [2]
1	2.33	2.33	2.33	0.00	0.00
2	4.59	4.45	4.58	3.05	0.22
3	4.61	4.54	4.66	1.52	1.08
4	2.31	2.26	2.45	2.16	5.96
5	2.33	2.33	2.33	0.00	0.00
6	1.24	1.14	1.27	8.06	2.42
7	2.35	2.36	2.22	0.43	5.47
8	2.33	2.33	2.33	0.00	0.00
9	0.95	0.95	6.49	0.00	583.32
10	2.30	2.33	2.33	1.30	1.30
11	2.32	2.33	2.33	0.43	0.43
12	6.55	6.49	6.49	0.92	0.89
13	1.02	1.06	0.90	3.92	11.57
14	2.09	2.18	2.14	4.31	2.59
15	2.88	2.70	2.45	6.25	15.01
16	1.28	1.23	1.37	3.91	7.03
17	4.42	4.37	4.38	1.13	1.00
18	1.16	1.30	1.26	12.07	8.45
19	4.21	4.61	4.38	9.50	4.13
20	2.33	2.33	2.33	0.00	0.00
APE (%)				2.95	32.54

It is clearly seen from the results given above that our calculated surface roughness values with the proposed expression are better than the obtained results by using suggestion given in [2]. This good agreement between the values of the experimental and our calculated surface roughness supports the validity of the surface roughness expression obtained using the ABC algorithm. Using the expression presented here, one can easily calculate the surface roughness of the AISI 1050 steel using a scientific calculator since it does not require complicated mathematical transformations of sophisticated functions.

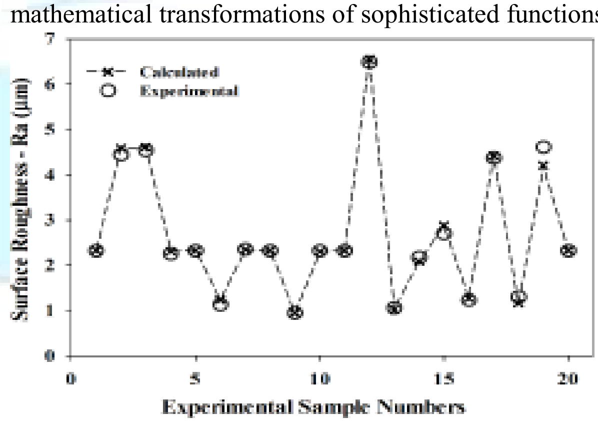
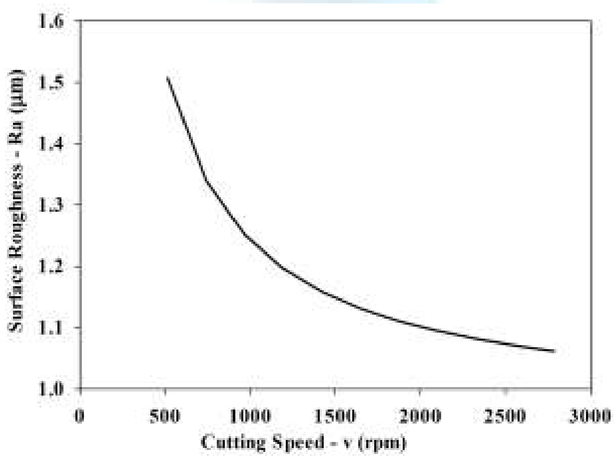
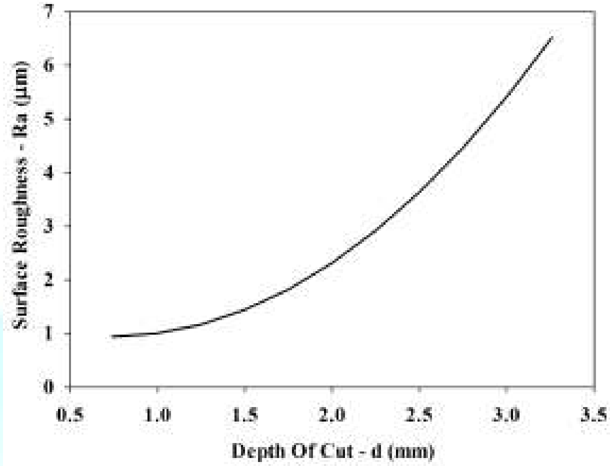


Fig. 2 The calculated and experimental surface roughness values

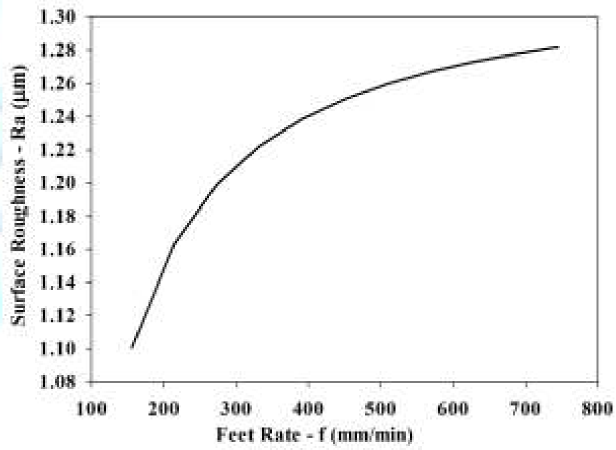
In order to examine the of the parameters on the surface roughness formulation, the plots shown in Fig. 3 is obtained with the help of the proposed formulation. While the values of parameters for plotting the figures are computed, a constant value is selected for two of the three parameters. Further, for another factor, the value of the factor is increased according to a certain rate value selected in the range of lower and upper values and Its effect on surface roughness is investigated. In Fig. 3a which identified the values of the feed rate and depth of cut as 294 mm/min and 1.26 mm, have shown the relationship of surface roughness and cutting speed. When the cutting speed value increases, the decreasing of the surface roughness is distinctly seen especially 500–1250 rpm range. As shown by Fig. 4, in fixed feed rate, increasing spindle speed makes closer the cutting tool path and the cutting tool path zone becomes purer surface. The relation of the among surface roughness with depth of cut is illustrated in Fig 3b. The values of feed rate and cutting speed have fixed for 1135 rpm and 294 mm/min. As the depth of cut increases, the surface roughness value rises. The depth of cut amounts makes more resistance makes more vibration to cutting tool during removing chips and naturally that cause the high surface roughness values. The changing in surface roughness has shown depending on the feet rate in Fig 3c. The values of cutting speed and depth of cut have selected 1135 rpm and 1.26 mm, respectively. The plot illustrating relation of surface roughness and the feed rate is given in Fig 3c. It is seen that the surface roughness increases while the feed rate rises. The cutting tool path distance gets higher against the increasing feed rate and that's affects the surface roughness.



(a)



(b)



(c)

Fig. 3 The effect of the parameters on surface roughness formulation: (a) surface roughness–cutting speed, (b) surface roughness–depth of cut and (c) surface roughness–feed rate

5. Conclusion

In the present study, a new, simple and surface roughness mathematical expression which results in accurately calculating the surface roughness of the AISI 1050 steel has been presented. To achieve this goal, an expression was derived by utilizing the twenty-experimental data for AISI 1050 steel, having different parameters such as the cutting speed, rate of feed, depth of cut by the ABC algorithm which is one of the most used evolution methods. The surface roughness results have been compared with a method reported in the literature. It was shown that the surface roughness values obtained from the surface roughness expression are in very good agreement with the results as compared with that calculated by the other method earlier. It is concluded that the advantages of expression presented in this work are the simple, and reliable.

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