Milling Machine Parameter Optimization by Grey Wolf Optimization (GWO)

Anil Mehta[1], Manish Kumar[2]
[1]*M.Tech Scholar, Dept of Mechanical , S G I, Samalkha Panipat*
[2]*A.P, Dept of Mechanical , S G I, Samalkha, Panipat*

Abstract: This work is focused to reduce the cost and time in tuning the parameters of milling machine in decreasing the surface roughness of composite of (Al_2O_3+SiC) which is used in aeronautical industry. We used grey wolf optimization to get the optimal set of four input parameters of the CNC milling machine and get 19% more improved results than simulated annealing applied on same. In this analysis we also described the most effective parameters in deciding the surface roughness in used composite object. We found that the feed and depth of cut are most affecting input parameters in milling machine whereas step over ratio is least affecting input variable.

I. INTRODUCTION

Metal cutting development, or more especially the machining advancement, is an indispensable piece of any mechanical amassing office. It is moreover considered as the most routinely used metal shaping procedure. The measure of theory being made all around in show day machine instruments for doing machining is seen as an advantage of a nation. Generally, the term metal cutting is portrayed as an undertaking in which a thin layer of metal or chip is removed from a greater body by using a wedge shaped instrument. The term machining can be described as a metal cutting strategy in which both the work piece and the gadget are held firm by a power-driven mechanical structure and the material ousted from the work piece in kind of chips is prompted by the relative development among gadget and work piece. Machining development finds its wide based application in a significant measure of organizations, for example: auto, aeronautics/carrier and home devices, to give a few illustrations. The forefront history of machining backpedals to the complete of the eighteenth century when the instruments made of set carbon steel were used to machine easy to-cut materials like dim cast iron, metal and bronze, other than fundamental turning of wood. The machining development has progressed starting there ahead and in different points. It has rolled out improvement in machine mechanical assembly structures, stream, power and solidness. Additionally, progression is seen and proceeding in cutting device tip substrates and its coatings; advancements in its geometry; in gadget and workpiece holding devices. Progression in conveying better control (NC and CNC) and refined machining programming.

Surface roughness is one of the most important parameters to determine the quality of a product. Surface roughness consists of the fine irregularities of the surface texture, including feed marks generated by the machining process. The quality of a surface is significantly important factor in evaluating the productivity of machine tool and machined parts. The mechanism behind the formation of surface roughness is very dynamic, complicated, and process dependent. Several factors will influence the final surface roughness in a CNC end milling operation such as controllable factors like CNC cutting speed, feed, depth of cut and step over ratio. Because of these dependencies researchers used several optimisation algorithms and latest simulated annealing (SA) was used to tune these parameters for optimum surface roughness of material. It has been seen that although SA gave better results than rest four but number of iterations required in SA was very high so the convergence time. Whereas a new Grey Wolf Optimisation (GWO) algorithm has proved better than SA in other non linear applications. So in our work we will try to remove this issue with less convergence time and better surface roughness.

In this work we used GWO optimization to improve the surface smoothness. Following sections will detail the GWO optimization, how GWO tunes the milling machine input parameters for targeted objective functions and results in last section.

II. GREY WOLF OPTIMIZATION (GWO)

grey wolf optimization is a new algorithm based on hunting behaviour of grey wolves. Wolves hunts into a group and encircle the prey. These wolves follow the hierarchical structure in the group to hunt down the prey. The wolf with best position with respect to prey is at the top level of hierarchy which gives command to others. The following two wolves with decreasing optimal value is at corresponding levels as shown in figure 2.1 [13].

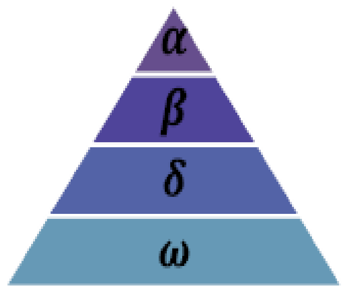

Fig 2.1. Hierarchy of grey wolf (dominance decreases from top down). [13]

The wolves encircle the prey and mathematically it can be written as;

$$D = |\vec{C}.\overrightarrow{X_p}(t) - \vec{X}(t)| \qquad (2.1)$$

$$\vec{X}(t+1) = \overrightarrow{X_p}(t) - \vec{A}.\vec{D} \qquad (2.2)$$

Here t shows the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vector, $\overrightarrow{X_p}$ indicates position vector of prey or $\vec{X}$shows position vector of grey wolf.

$\vec{A}$ And $\vec{C}$ both are calculated as:-

$$\vec{A} = 2\,\vec{a}.\vec{r_1} - \vec{a}$$

$$\vec{C} = 2.\vec{r_2}$$

Here components of a are linearly decreased from 2 to 0 of iterations and r1, r2 both are random vectors in [0, 1].

During hunting the prey the alpha guides the beta and delta wolves since it is at the best optimal position w.r.t. prey so far. The algorithm considers that alpha, beta and delta wolves are at optimal positions than others, so keeping these three's positions in consideration, other wolves are updated as:

$$\overrightarrow{D_\propto} = |\overrightarrow{C_1}.\overrightarrow{X_\propto} - \vec{X}|,\ \overrightarrow{D_\beta} = |\overrightarrow{C_2}.\overrightarrow{X_\beta} - \vec{X}|, \overrightarrow{D_\delta} = |\overrightarrow{C_3}.\overrightarrow{X_\delta} - \vec{X}| \quad \ldots(2.3)$$

$$\overrightarrow{X_1} = \overrightarrow{X_\propto} - \overrightarrow{A_1}.(\overrightarrow{D_\propto}), \overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2}.(\overrightarrow{D_\beta}), \overrightarrow{X_3} = \overrightarrow{X_\propto} - \overrightarrow{A_3}.(\overrightarrow{D_\delta}) \qquad (2.4)$$

This process is shown in graph 2.2

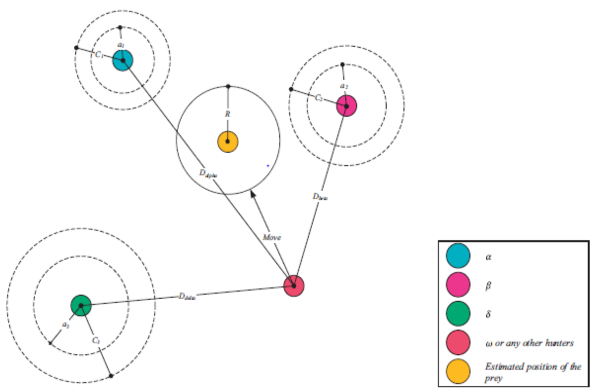

Fig. 2.2. Position updating in GWO. [13]

When prey is encircled by equations 2.1 and 2.2 then the $\vec{a}.\vec{A}$ is reduced from [-2a to 2a] to get near to prey where $\vec{a}.$ reduces from 1 to 0 as shown in figure 2.3.

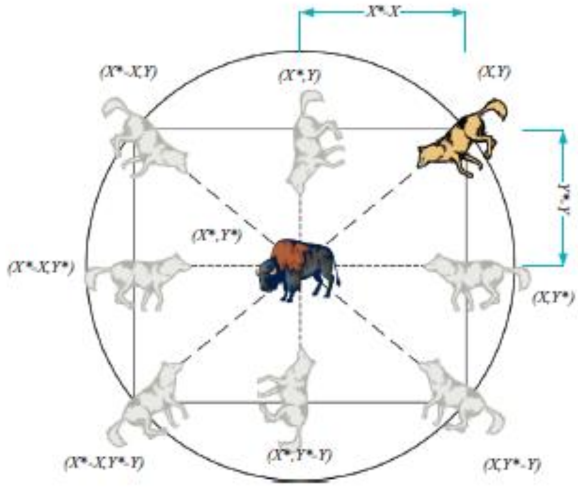

Fig. 2.3: 2D position vectors and their possible next locations. [13]

III. PROPOSED SOLUTION

As discussed we are testing the proposed algorithm for the Aluminium composite Al_2O_3+SiC. Linear regression and non linear regression tests are performed mathematically. We developed the MATLAB script for GWO which optimises the input parameters of CNC milling machine. These input parameters are speed of cut, depth of cut, feed and step over ratio. The experimental test to get a very smooth object for various combination of input parameters will waste the material a lot and increases the cost and time in the project. To avoid these we used simulation of experiment and get the optimized set of input parameters in no time which are approximate to saturation point. Grey Wolf Optimization (GWO) is used to select optimal parameters of milling machine. The surface roughness is the objective function which needs to be minimized. The linear equation which relates the surface roughness with four optimising parameters is given in equation 3.1.

$$R_a = 0.893 - 0.0028x_1 + 0.00186x_2 + 1.19x_3 + 3.39x_4 \quad \ldots\ldots.3.1$$

Where R_a is surface roughness in µm

$x_1$is speed in m/min

$x_2$is the feed in µm /rev

$x_3$is the depth of cut mm

$x_4$is the step over ratio

Similarly non linear relation between them is also established which is represented in equation 3.2.

$R_a = 1.99 - 0.454\log_{10}x_1 + 0.124\log_{10}x_2 + 0.157\log_{10}x_3 + 0.794\log_{10}x_4$ 3.2

GWO is discussed in section 3, the positions of grey wolves are equivalent to input parameters to milling machine. Since we have four input parameters, so a wolf's position is also represented by these four values. Each wolf tends to reach at prey's position which is the best optimum solution. In our application, The prey's position is the position for which surface roughness is minimum as it is the best optimal solution for milling machine case. To get near to this optimal position each wolf calculates the difference between the roughness value by its present position and best roughness value so far. The wolf steps to minimize this difference. For the first iteration, wolves positions are chosen randomly within searching space area and the best optimal solution is considered zero. Three best solutions are selected as discussed in section II and mean of their updated positions is the updated position for every wolf which is converging towards the prey. For this new position of wolves, new surface roughness value is calculated and compared with previous best solution. This process keeps on repeating till all iterations are not finished. The algorithmic steps for the whole process are as:

Step1. input the upper and lower bounds for machine input parameters as in table 4.2.

Step2. initialize the positions of 20 wolves randomly for the first iteration and update these till 100 iterations.

Step3. for each wolf position calculate the surface roughness for linear and non linear regression using equation 4.1 and 4.2.

Step4. save the 20 roughness values into a table for 1st iteration and arrange them in increasing order.

Step5. top 3 minimum surface roughness values are selected and corresponding wolves are assigned as α_wolf , β_wolf and γ_wolf.

Step6. Update these three positions using equation 3.1 and 3.2.

Step7. Mean of these three new positions is considered as the new position of each wolf towards the convergence point in the searching space.

Step8. Surface roughness for these new positions of 20 wolves is calculated again

Step9. repeat the steps from 4-7 till all iterations are finished.

Step10. Finally settled saturation position of wolf for which no more convergence is achieved is the optimal values of CNC milling machine input parameters.

The terms used in GWO is significant in CNC milling machine's parameter optimisation. This equivalent significant terminology is shown in table 3.1.

Table 3.1: Grey Wolf optimization terminology equivalent to CNC machine

GWO terms	**CNC machine optimization**
Position of wolves	CNC machine input parameters
Searching space for prey by wolves	Maximum and minimum limits of input values to select the optimal
Prey's position	Final optimal set of CNC machine values
α_wolf	Best set of CNC input parameters

IV. RESULTS

This work is developed in MATLAB and completely simulation work. Results are tested and compared with Simulated annealing (SA) optimisation for both linear and non linear regression analysis. The convergence curve between GWO and SA optimization is drawn in figure 4.1. The minimum is the slope and earlier is the saturation point, better are results.

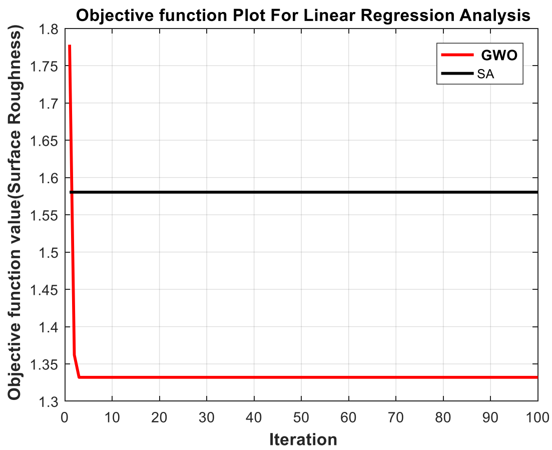

Figure 4.1: optimisation curve for linear analysis for GWO and Simulated Annealing (SA)

The surface roughness obtained for final tunes input parameters set is 1.33 and 1.66 with GWO and SA respectively which is 20.5% less than SA. Table 4.1 shows the finally settled input values to milling machine for linear regression analysis.

Table 4.1: Output tuned parameters for three optimisation algorithms by linear analysis

	Sped of m/c in m/min	**Feed in µm /rev**	**Depth of cut on mm**	**Step over ratio**	**Surface Roughness in µm**
GWO	6000	100	0.2	0.5	1.33200
SA	5675.69	100	0.4	0.5	1.66

Similarly, for the non linear regression analysis the final values are 0.17 and 0.21 for GWO and SA which is 19% lower than SA. Table 4.2 lists the final tuned sets for both methods for comparison.

Table 4.2: Output tuned parameters for three optimisation algorithms by non-linear analysis

	Sped of m/c in m/min	**Feed in µm /rev**	**Depth of cut on mm**	**Step over ratio**	**Surface Roughness in µm**
GWO	6000	100	0.2	0.5	0.17396
SA	5998.94	100	0.29	0.52	0.2149

The comparison of non linear and linear analysis for proposed solution is shown in graph 4.2.

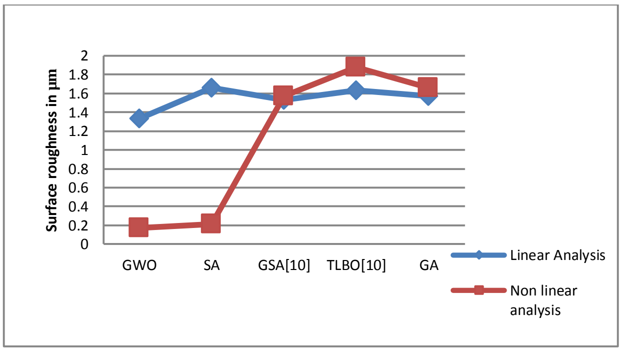

Figure 4.2: Comparison of Surface roughness for non linear and non linear regression

Above figure clearly demonstrates that minimum surface roughness is obtained in case of on linear regression analysis by our proposed GWO optimization. If linear regression case is considered than also proposed algorithm out pass others. A figure 5.6 is plotted to check the dependency of surface roughness over each input variable to CNC machine. The graph is plotted for surface roughness vs normalized independent variables to bring all four at same scale as all of them are differing by a large scale, for example speed is in between 2000-4000 rpm and depth of cut is in between 0.2-0.4.

From figure 4.3, it is clear that the graph of depth and feed in machine has larger slope than others and surface roughness value shows more dependency over these as compared to others. So depth of cut and feed values contribute more in minimising the roughness. The step over ratio has almost negligible affect and maintains it fixed value during optimization.

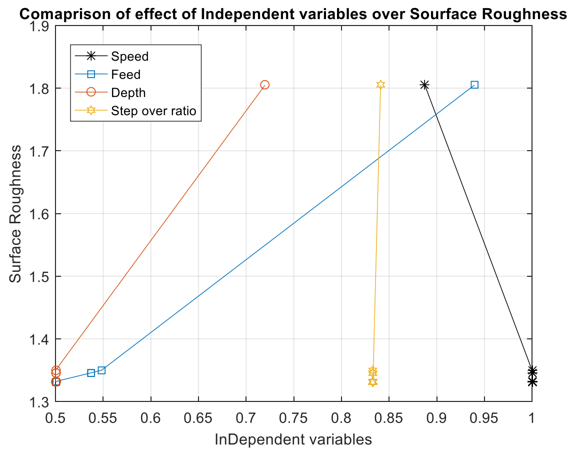

Figure 4.3:surface roughness comparison for both linear and non linear analysis

As per the slop of four graphs in above figure the most effective input parameter for surface roughness is as in given sequence:

1. feed
2. depth of cut
3. speed
4. step over ratio

V. CONCLUSION

We used a new Grey Wolf optimization (GWO) algorithm which tunes the input parameters of milling machine keeping the minimum surface roughness of the object in consideration. The advantages of converting the testing of surface roughness on machine to simulation are: it saves the cost of experiment as no more requirement to mile the object repeatedly for different input settings in machine, saves time and simulation gives quick and approximate input variables set. We considered four tuning parameters of CNC machine: depth of cut, speed of cut, feed and step over ratio. In 100 iterations of GWO, different 100 sets of these values are tested and the one with minimum surface roughness is finalised. All these 100 values are not randomly chosen but varies to converge towards a minima point within a searching space boundary. Surface Roughness thus obtained is compared with a recent optimization technique used for the same purpose and for linear regression case we get 20.5% improvement in results and 19% for the non linear regression analysis.

VI. REFERENCES

[1]. C. Manikandan, B. Rajeswari "Cutting Parameters On Drilling EN24 Using Taguchi Method" International

Journal of Engineering Research and Technology (IJERT) - 7, July – 2013

[2]. SrinivasaReddy,S. Suresh, F. AnandRaju, A. Gurunadham "Assurance of Optimum Parameters in CNC Drilling of Aluminum Alloy Al6463 by Taguchi Method" International Journal of Engineering Research and Technology (IJERT-) - 2, February - 2014

[3]. Prof.Dr.NabeelKadimAbid Al-Sahib, HasanFahadAbdulrazzaq, Thi-Qar University, Al-Jadriya , Baghdad, Iraq "Device Path Optimization of Drilling Sequence in CNC Machine Using Genetic Algorithm" Innovative Systems Design and Engineering.1, 2014

[4]. Nakandhrakumar R S "Versatile Optimization utilizing Gray Relational Analysis and PID Control of CNC Drilling Process" International Conference on Robotics, Automation, Control and Embedded Systems - 18-20 February 2015

[5]. Kunal Sharma, Mr.AbhishekJatav "Streamlining of Machining Parameters in Drilling of Stainless Steel International Journal of Scientific Research Engineering and Technology (IJSRET)" - 8, August 2015

[6]. KrupalPawar and R. D. Palhade " Multi-target Optimization of CNC Turning Process Parameters for High Speed Steel (M2) Using Taguchi and ANOVA Method" International Journal of Hybrid Information Technology (2015)

[7]. K.G.Durga Prasad, M.V.Prasad and K.VenkataSubbaiah " Optimization of Process Parameters in CNC End Milling of Glass - Fiber Reinforced Plastic" International Journal For Research In Emerging Science And Technology" - 6, JUN-2015

[8]. H. Abdullah1, R. Ramli1, D. A. Wahab1, J. A. Qudeiri "Reproduction Approach Of Cutting Tool Movement Using Artificial Intelligence Method" Journal of Engineering Science and Technology - June 2015

[9]. KhashayarDaneshNarooei "Device Path Optimization for Drilling Process by CNC Milling Machine Using Ant Colony Optimization (ACO)"JANUARY 2014

[10]. Vikas Pare – GeetaAgnihotri – Chimata Krishna "Determination of Optimum Process Parameters in High Speed CNC End-Milling of Composite Materials Using Meta Heuristic Techniques" Journal of Mechanical Engineering-2015

[11]. N.V.MaheshBabuTalupula "Test Investigation Ofoptimal Machining Parameters Of Mild Steel In Cnc Milling Using Particle Swarm Optimization" IPASJ International Journal of Computer Science (IIJCS) 1, January 2015

[12]. R. Venkata Rao," Review of uses of TLBO calculation and an instructional exercise for fledglings to settle the unconstrained and compelled advancement issues", Decision Science Letters 5(1):1-30 • January 2016

[13]. Seyedali Mirjalili, Seyed Mohammad Mirjalili, Andrew Lewis, "Grey Wolf Optimizer", Advances in Engineering Software, Volume 69, 2014

[14]. R. Venkata Rao ∗ , Vivek Patel," An enhanced educating learning-based improvement calculation for tackling unconstrained advancement issues", ScientiaIranica Volume 20, Issue 3, June 2013, Pages 710– 720

[15]. Baghlani, M. H. Makiabadi," Teaching-Learning-Based Optimization Algorithm For Shape And Size Optimization Of Truss Structures With Dynamic Frequency Constraints", IJST, Transactions of Civil Engineering, Vol. 37, pp 409-421

[16]. Kai-Lin Wang , Hui-Bin Wang , Li-Xia Yu , Xue-Yu Ma , Yun-Sheng Xue," Toward Teaching-Learning-Based Optimization Algorithm for Dealing with Real-Parameter Optimization Problems", Proceedings of the second International Conference on Computer Science and Electronics Engineering (ICCSEE 2013)

[17]. Degarmo E. P., Black J. T., Kosher R. A., "Material Processing in Manufacturing", eighth version, upper seat waterway, NJ, Prentice Hall, 1999.