Novel Hybrid PSO-GWO Optimization to Tune CNC Milling Parameters

Bhupender and Balinder Singh
M.Tech (ME) Scholar, Bahra Institute of Management and Technology
Asst.Proff. ME Department, Bahra Institute of Management and Technology

Abstract- In this study, the main focus is to reduce the surface roughness of a composite material using a CNC milling machine. Usually, the roughness achieved in CNC machine depends upon the input parameters combination and testing different combinations is not a practical approach. So in previous literature, metaheuristic optimization algorithms were used as the mathematical formulation of milling machine problems become NP-hard problem. We also followed the line but with improved results with the latest hybrid optimization called GWO-PSO. It is the combination of two metaheuristic optimization algorithm. The mathematical equations are developed for aluminum metal composites (Al_2O_3 + SiC) as it has significant applications in aeronautics industries. From the recent literature study, we found that previous latest work was done using GWO optimization algorithm and compared with various others. We compared results of our optimization with that and proved the improvement up to 19%. Linear and non linear regression analysis are performed and four different input parameters are considered which are; feed and step over ratio, speed, depth of cut. GWOPSO tunes these four parameters to get the minimum surface roughness using a script written in MATLAB. Both linear and nonlinear regression analysis performed better than the GWO optimized values outcome. The improvement in surface smoothness is achieved is 20.5% than GWO in linear regression analysis and 19% in non linear regression analysis.

Keywords- CNC machine, Surface roughness, VHO, HHO, Hybrid Optimization, PSO, GWO, etc.

I. INTRODUCTION

In the present days, the metal cutting improvement and advancement of the machining tool is the key aspects for the mechanical field. The small and large size CNC based machines have major applications in the field of fabrications like power material, aerospace and automotive. The metal shaping process is a commonly used method in machining technology. The metal cutting, with the help of a machine, is called the machining process. In this process, both the object (job) and tool are fixed in a frame where the waste material is cut out from the job by the tool via power drive mechanical architecture. The metal cutting is the basic part of the machining process, and it has a wide range of applications in terms of key mechanical field.

A. Milling Machine-

The work piece is affixed to the processing machine desk and is sustained against the rotating milling shaper. The milling shaper can have cutting teeth on the outskirts or side or both. Various types of milling available in the market;

Slab Milling

In piece processing, likewise called fringe processing, the pivot of shaper turn is equivalent on the workpiece plane to be machined. The Cutter used for large piece processing may have straight or helical teeth bringing about the separately orthogonal or slanted cutting activity.

Face Milling

It is used to cut the flat surface into the workpiece. It is the most effective process of milling machine which applied to mill the plane surface. The setup of the milling machine depends on the structure of the workpiece, size, and location of the surface, quantity of workpiece, and material of the workpiece.

End Milling

A level surface and additionally different profiles can be delivered by end milling. The shaper in end milling has either straight or decreased shanks for littler and bigger shaper sizes separately. The shaper normally pivots on a hub opposite to the workpiece, even though it can be tilted to machine-decreased surface.

B. CNC machine

The computer numerical control (CNC) milling machine provides the custom design and shape to the material. It provides computer control and moving multiple point cutting equipment which removes extra material from a workpiece. The CNC can be applicable in the various material shaping applications like metal, plastic, wood, and glass. In CNC machining process, several capabilities are presented like electrical, mechanical, chemical, and thermal. Lots of machining process like cutting, drilling, and turning is performed by CNC machine. The entire operation of the CNC machine explained in steps;

- Prepare the CAD model
- Conversion of CAD model into CNC script
- Adjustment of CNC machine

- Delivered the milling operation

Fig.1: CNC milling machine [5]

C. Objectives

We optimized the different parameters of CNC machine like step cut, depth ratio and surface roughness. These parameters were optimized by, several approaches like SA (Simulated Annealing) and GWO (Grey Wolf Optimization) in the previous year. The GWO algorithm selects the optimal value of these parameters, and best-fit surface roughness was achieved. We modified the GWO work by combining the properties of GWO and PSO. We developed a hybrid GWO algorithm which provided better results than the previously proposed algorithms. So in our work, we will try to remove this issue with less convergence time and better surface roughness. The following objectives are considered in the study;

- To obtain the maximum value of surface roughness based on CNC parameters.
- To control these independent parameters, a new hybrid GWO-PSO optimization scheme will be proposed.
- To compare all the results like the regression relationship for dependent and independent variables with the previous GWO optimized work.

II. RELATED WORK

As discussed earlier in previous section various techniques were proposed for the metal finishing and cutting mechanism using the CNC and milling machine. Taguchi method [2] proposed for the selection of cutting parameters of various materials and applications. The genetic algorithm in [3] improved the efficiency of the CNC machine without affecting the output parameters. In [4] Taguchi method applied for the stainless steel finishing operations on CNC machine and in [7] Taguchi method used for the GFRP material. The Genetic algorithm and ACO (ant colony optimization) algorithm proposed in [8] for the measuring instrument development using CNC. The PSO optimization also proposed for the material surface minimization in [11,15]. TLBO approach proposed with PSO and other optimization in [12, 13, and 14]. We get an idea of hybrid optimization from [13] in which PSO and TLBO combination applied to improve the parameters of the CNC machine which provided effective results. A Hybrid approach PSO-GWO proposed for the benchmark function evaluation in [19], which provided better results than the GWO optimization. We can implement PSO-GWO method for the surface roughness minimization using a CNC machine.

III. OPTIMIZATION

Optimization is the process of finding the best value for the variables of a particular formulation to maximize or minimize an objective function called as an optimization. Optimization used in the various fields of research. There is two basic need of the optimization process, the parameters of the problem are identified by their nature (problem can be analog or digital), and constraints which applied to the parameters have to be recognized. The objective function of the given problem should be identified which can be classified as a single objective and multi-objective.

a. Particle Swarm Optimization

The PSO basic principle is the copied the nature of bird flocking. In this the group of birds are present in the search space for finding the food. The birds not know the exact location of the food. So all the birds make rules, the bird which is very close to the food others birds will follow that bird for find the location of the food. The process will be done for the large number of times. When an bird find exact position or location of the food it will be the best value of algorithm. The algorithm is also developed like the bird rules for searching the food location. It can be used in the optimization application very easily. Here the optimal value which we find is the bird in the search space. In algorithm the bird calls particle. There are number of particles present in the space with having fitness value as per the objective function given to them. Firstly initialize all the parameters of the algorithm then find the fitness value for all the particles. The velocity concept is very important in case of PSO. All the articles not has same velocity so the final position or location is updated by adding the velocity to the particle fitness value [18].

The group of random particles searching for the best position of the fitness value. For each iteration every particle modified by the two best fitness values. The first value is called pbest value and another best value is called the global best values which are calculated by the particle swarm optimizer. When the nearest particle shares the values with other particles this value is called local best value. It is represented by lbest [18]. The position and velocity equation of the PSO algorithm is updated by the obtained two best values above and the equation written below. Equation 1 and 2 shows the velocity update and position update according to the PSO.

$$V_i^{K+1} = (c_1 r_1 (X_1 - X_i^k) + c_2 r_2 (X_2 - X_i^k) + c_3 r_3 (X_3 - X_i^k) \quad (1)$$

$$X_i^{K+1} = X_i^k + V_i^{K+1} \quad (2)$$

V_i^{K+1} =particle velocity as per the local best and global best value, $r_1 r_2$ =are the random number choose, $c_1 c_2$ =are the constants value, X_i^k =initial position of the search agents, X_i^{K+1}=updated position after velocity [18].

b. GWO (Grey Wolf Optimization)

The grey wolf optimization algorithm inspired by the hunting behavior of the wolves. The wolfs are lived in a group. There is 5 to 12 member of wolfs present in a group. The wolfs are the top of the food chain. The dominance of wolfs in a group decreases from top to down. As shown in the figure, there are three categories of wolfs.

Alpha (α) are the leaders of the group which have the authority to take a decision. They may be male and female which responsible for the making decision like hunting, place of sleeping and so on.

The next member is Beta (β) wolves in the group. The beta can be male or female, and he/she plays the role of advisor to alpha. The beta wolves help the alpha wolves in decision making and providing a command to the lower member of the group [13].

The lower member of the wolves group is omega (ω). The omegas play the role of scapegoat. They are the last member of the group which allowed eating.

The new wolves delta (δ) are subordinate of the alpha, beta and omega. If a wolf is not alpha, beta and omega, then he/she are a subordinate [9].

The mathematical expression of wolves **encircle prey** in the hunting process shown in the equations

$$E = \overrightarrow{F}.\overrightarrow{G_p}(k) - \vec{G}\,(k)| \quad (3)$$

$$\vec{G}(k+1) = \overrightarrow{G_p}(k) - \vec{P}\,.\vec{E} \quad (4)$$

The P and $\vec{Q}$ are a coefficient vector, $\vec{G}$ reflects the position vector the grey wolf, k represents the current iteration,$\overrightarrow{G_p}$ is the position vector of prey. The formulation of the coefficient vector showed in the equation 5 and 6.

$$\vec{P} = 2\,\vec{p}\,.\overrightarrow{b_1} - \vec{p} \quad (5)$$

$$\vec{Q} = 2.\overrightarrow{b_2} \quad (6)$$

The range of the component p is from 2 to 0 and b_1, b_2 both are random vectors in [0, 1].

The alpha usually guides hunting, but beta and delta also play a vital role in obtaining the best position of the prey. We consider the alpha is the best solution and bêta; delta provides the location of prey. We save three best solution obtained so far and omega values update as per the best position of the search agent [13].

$$\overrightarrow{E_\alpha} = |\overrightarrow{Q_1}.\overrightarrow{G_\alpha} - \vec{G}| \quad (7)$$

$$\overrightarrow{E_\beta} = |\overrightarrow{Q_2}.\overrightarrow{G_\beta} - \vec{G}| \quad (8)$$

$$\overrightarrow{E_\delta} = |\overrightarrow{Q_3}.\overrightarrow{G_\delta} - \vec{G}| \quad (9)$$

$$\overrightarrow{G_1} = \overrightarrow{G_\alpha} - \overrightarrow{P_1}.(\overrightarrow{E_\alpha}) \quad (10)$$

$$\overrightarrow{G_2} = \overrightarrow{G_\beta} - \overrightarrow{P_2}.(\vec{E}) \quad (11)$$

$$\overrightarrow{G_3} = \overrightarrow{G_\delta} - \overrightarrow{P_3}.(\overrightarrow{E_\delta}) \quad (12)$$

$$\vec{G}(K+1) = \frac{\overrightarrow{G_1}+\overrightarrow{G_2}+\overrightarrow{G_3}}{3} \quad (13)$$

The vector $\vec{a}$ use to control the trade off between exploration and exploitation phase, the range of this vector between 0 to 2.

$$\vec{a} = 2 - t.\frac{2}{Max_{iter}} \quad (14)$$

IV. PROPOSED WORK

In this work we worked towards improving the surface roughness of aluminium silicon carbide (Al-SiC) composite using CNC milling machine. Our work is mainly focused on the optimising the machine parameters to get the maximum surface smoothness of job. The linear equation which relates the surface roughness with four optimising parameters is given in equation 6.

$$R_a = 0.893 - 0.0028x_1 + 0.00186x_2 + 1.19x_3 + 3.39x_4 \quad (15)$$

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. Here these four variant of 'x' are input parameters if CNC machine whereas surface roughness is the output parameter observed over processed job on CNC. Similarly non linear relation between them is also established which is represented in equation 7.

$$R_a = 1.99 - 0.454\log_{10}x_1 + 0.124\log_{10}x_2 + 0.157\log_{10}x_3 + 0.794\log_{10}x_4 \quad (16)$$

All notations have same significance as in equation 6. These parameters must be set to get an optimum value so that minimum surface roughness can be achieved. The optimization algorithm will not test the job in actual but implement the behaviour of job object into software program and gives the optimal input value set for milling machine. GWOPSO is latest technique and helps us to get the optimal answer to our non linear problem. GWOPSO and milling machine are two isolated systems but these are linked through a feedback system.

a. Hybrid GWO-PSO tune the CNC paramters

The hybrid Particle Swarm Optimization and Grey Wolf Optimization algorithm is low level because we merge the functionalities of both of them. Both the algorithms are run in parallel. The search agents position is randomly search. The each search agents have different upper and lower bound limits. Calculate the initial position of the search variable. We initialize the parameters of algorithm, generate and also evaluate the initial position, and then determine the best solution in the position. Then update the position of the search agents. After updating the position the upper and lower bound limits are applied and update the position of search agents by using equation [19].

GWO-PSO starts with random values of wolves positions which are the values of CNC's four inputs. In an iteration, in our application 20 wolves are considered in a group which means we have 20 different set of CNC machine input and for each set surface roughness is calculated. Out of these 20 values, minimum value is indexed and the wolf's position for which this minimum value is obtained is made leader of group and comes at top level into hierarchy. This is called alpha wolf with most optimal way to hunt's position. Further the position values of each wolf is updated by following the equations 1 and 3. Top three best positions of wolves are identified for which surface roughness values is minimum. The position of the swarm updated as per the best position computed by GWO. The velocity and position update of PSO with the help of GWO.

$$V_i^{K+1} = w \times (c_1 r_1 (X_1 - X_i^k) + c_2 r_2 (X_2 - X_i^k) + c_3 r_3 (X_3 - X_i^k)) \quad (17)$$

$$w = 0.5 + \text{rand}()/2 \quad (18)$$

It can be done by arranging the 20 surface roughness values in decreasing order and top three indexes of wolves (three best set of input values to CNC machine so far) are updated by equation 10, 11 and 12. The optimal solution of CNC milling parameters is obtained by combining the GWO-PSO [19].

b. Steps for overall process

Step1. input the upper and lower bounds for machine input parameters

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 15 and 16

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. Using alpha, beta and delta update the velocity and position of swarm in PSO.

Step7. Mean of these three new positions is considered as the new position of each swarm and their velocity 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 swarm for which no more convergence is achieved is the optimal values of CNC milling machine input parameters.

Each Optimization algorithm require an objective function to minimize and in our case it is surface roughness function which is calculated by speed of cut, depth of cut, step over ratio and feed into the machine.

V. RESULTS AND DISCUSSION

Initialization of proposed optimization requires only number of wolves in a group to tune manually for better results. We compared our results with previous work in which GWO was used. These are those algorithms for which we have developed MATLAB scripts and a comparison between them will be discussed further. What makes to declare any optimization algorithm as best algorithm or to judge that optimized values are really optimum? Any optimization algorithm's efficiency is judged by analyzing the behavior of that with each iterations. The objective function value must be decreasing or increasing as per the case (in our case it must be decreasing) with number of iterations. An algorithm will be said good if quickly settles to an optimum value.

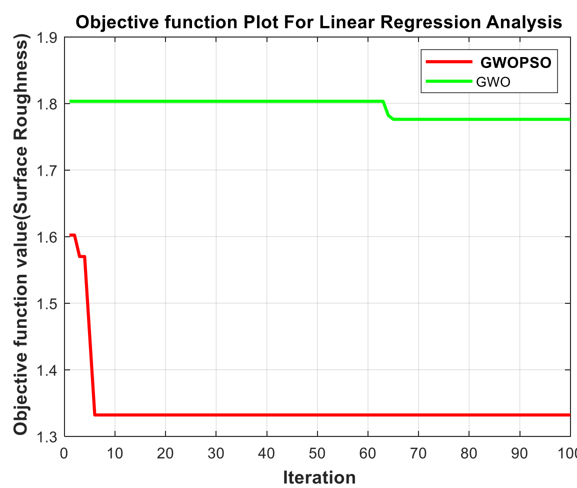

Fig.2: optimization curve for linear analysis for GWOPSO and GWO

The optimization curve in figure 2 is the convergence curve between surface roughness calculated in each iteration vs number of iterations. The minimum is the graph's final saturated value better is the optimization. Comparison of GWOPSO and GWO optimization is shown in the graph and GWOPSO attains a minimum value in both whereas GWOPSO also settles earlier to a saturation point.

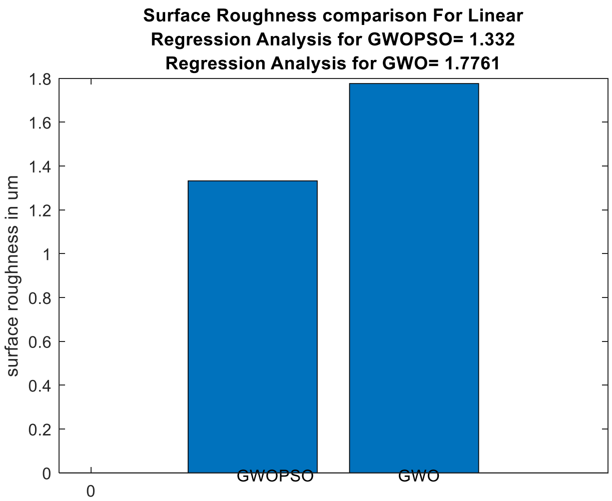

Fig.3: bar graph comparison of surface roughness for linear mathematical formulation

The surface roughness for both calculations is appeared in bar graph in figure 3. It demonstrates that hybrid GWOPSO gives the less roughness than GWO optimized parameters. These finally tuned set of parameters are shown in table 1 The finally achieved surface roughness by hybrid GWOPSO is 20.5% less than SA.

Table 2 shows the comparison of output of our surface roughness values and values calculated in reference paper [10]. That paper has compared surface roughness by four different algorithms: genetic algorithm (GA), Grey wolf optimization (GWO), TLBO and GSA.

Table 1 Output tuned parameters for three optimization 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**
GWOPSO	6000	100	0.2	0.5	1.33200
GWO	5675.69	100	0.4	0.5	1.66

We will compare these all values with our designed algorithm. The table clearly indicates that our proposed optimization algorithm is the winner even in convergence speed as compared to minimum in the table which is 5 iterations for TLBO as per paper. Though, good thing is that surface roughness is decreased more in our developed script. We have achieved the improvement of 15.29% from the minimum value (GWO) of paper by GWOPSO algorithm.

Table 2: comparison of surface roughness by various optimization algorithms in case of linear analysis

	GWOPSO	**GWO**	**GSA [10]**	**TLBO [10]**	**GA**
Surface Roughness in µm	1.332	1.71	1.53	1.63	1.57
Convergence speed	4	100	1000	5	51

Table 3 comparison of surface roughness by various optimization algorithms in case of non-linear analysis

	GWOPSO	**GWO**	**GSA [10]**	**TLBO [10]**	**GA**
Surface Roughness in µm	0.17396	0.2149	1.57	1.88	1.66
Convergence speed	3	100	1000	5	59

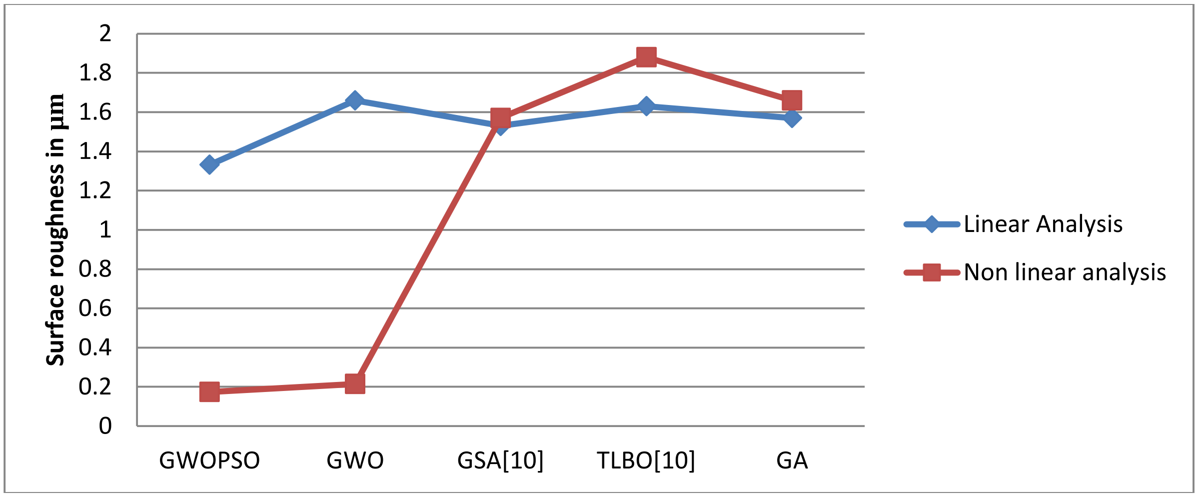

Fig.4: Comparison of Surface roughness for non linear and non linear regression

Above figure clearly demonstrates that minimum surface roughness is obtained in case of on linear regression analysis by our proposed GWOPSO optimization. If linear regression case is considered than also proposed algorithm out pass others. A figure 4 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 5, 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 minimizing the roughness. The step over ratio has almost negligible affect and maintains it fixed value during optimization.

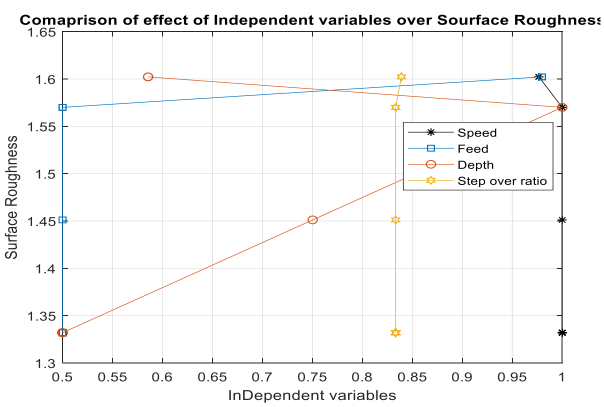

Fig.5: surface roughness comparison for both linear and non linear analysis

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

We plotted a 3D surface view to show the change in surface roughness values during the GWOPSO optimization process with step over ration and feed in figure 6 and figure 7 shows it for depth of cut and speed with surface roughness.

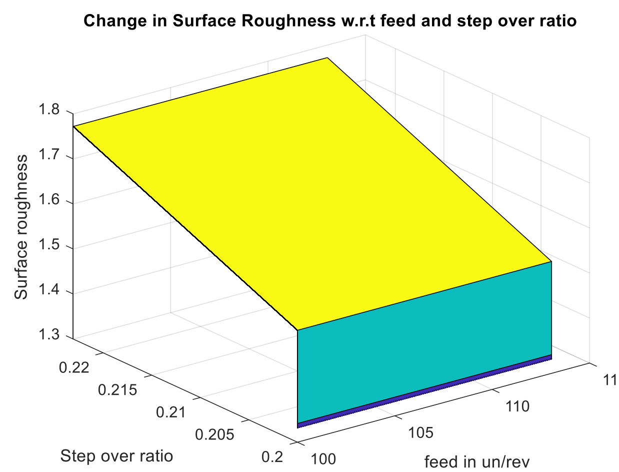

Fig.6: 3D surface plot for surface roughness vs step over ratio and feed in milling machine

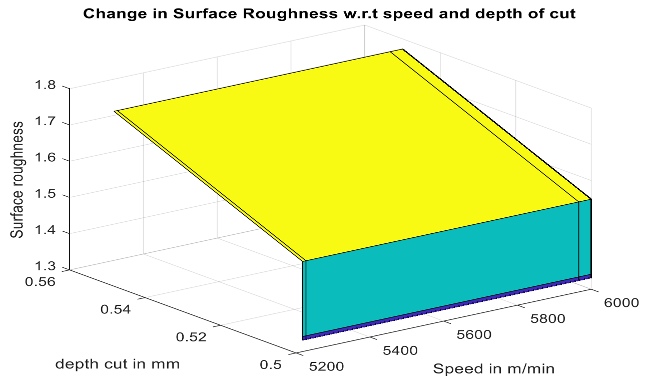

Fig.7: 3D surface plot for surface roughness vs depth of cut and speed in milling machine

V. CONCLUSION

Our work is presenting the milling machine's improved ability to minimize the surface roughness of a composite job object Al_2O_3 + SiC. We developed a hybrid algorithm by using Gray Wolf (GWO) and Particle Swarm (PSO) Optimization algorithms (GWOPSO) which tunes the input parameters of milling machine keeping the minimum surface roughness of the object in consideration.

In 100 iterations of GWOPSO, 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.

[18]. Mei-Ping Song and Guo-Chang Gu, "Research on particle swarm optimization: a review," *Proceedings of 2004 International Conference on Machine Learning and Cybernetics (IEEE Cat. No.04EX826)*, Shanghai, China, pp. 2236-2241 vol.4, 2004.

[19]. Narinder Singh and S. B. Singh, "Hybrid Algorithm of Particle Swarm Optimization and Grey Wolf Optimizer for Improving Convergence Performance," Journal of Applied Mathematics, vol. 2017, Article ID 2030489, 15 pages, 2017