Parametric Optimization of Face Milling Using Harmony Search Algorithm

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***Abstract*- Harmony Search (HS) Algorithm is used to determine the optimum cutting parameters for face-milling. In this work, an attempt is made to determine the optimum value of machining parameters i.e depth of cut, speed and feed rate are obtained for the improvement in the surface roughness with objective to minimize the total production cost. The research work of considering actual constraints such as allowable speed, feed rate, surface finish, tool life with the help of experiments on Vertical Machining Centre (DNM 500) for a specific(Plastic composite) material GFRP (Glass Fibre Reinforced Plastic). The results obtained from Harmony Search Algorithm are validated with the help of Genetic Algorithm (GA). HSA has given optimum solution with higher accuracy and efficiency in comparison with GA.**

***Key words* - Milling, Optimization, Harmony search algorithm, Genetic algorithm, cost minimization.**

I. INTRODUCTION

The cost, time and quality of production are highly dependent on the cutting parameters such as the number of passes, depth of cut, speed, and feed. So, determination of optimal cutting parameters with regard to technological requirements, capability of machine tool, cutting tool and the part material is a crucial task in the process planning of parts. The quality and productivity of the parts produced by milling process is highly depends upon various process parameters used in this process. So, the selection of efficient machining parameters is of great concern in manufacturing industries, where economy of machining operation plays a key role in the competitive market. The main objective of this work is to optimize the total production cost in face-milling operation. The optimum number of passes and optimal values of the cutting parameters are found by harmony search algorithm which is a recently developed meta-heuristic algorithm. An illustrative example is used to demonstrate the capability of the HS algorithm. For validation purpose GA is used to solve the same problem and the HS results will be compared with those of GA.

II. MATHEMATICAL FORMULATION

Here brief overview of the face-milling is provided, and then the mathematical model of this operation is presented.

Face milling

The machining operation can be divided into roughing and finishing operation, as shown in Fig : 1 In rough machining, the length of the cutter travel is given by

$$L_r = L + a_p + \mathrm{b}$$

Where L is the length of the work piece, a_p is the approach distance and b is an arbitrary distance to avoid possible accidents and damages. Here, for simplicity the parameter b is taken to be zero. The approach distance for symmetrical milling is Given as:

$$a_p = \left(\frac{D}{2}\right) - \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{w}{2}\right)^2}$$

where D is the diameter of the tool and w is the width of work-piece.

In finish machining, the relation $L_f = L + D + b$

L_f is the cutter travel length for the finish pass.

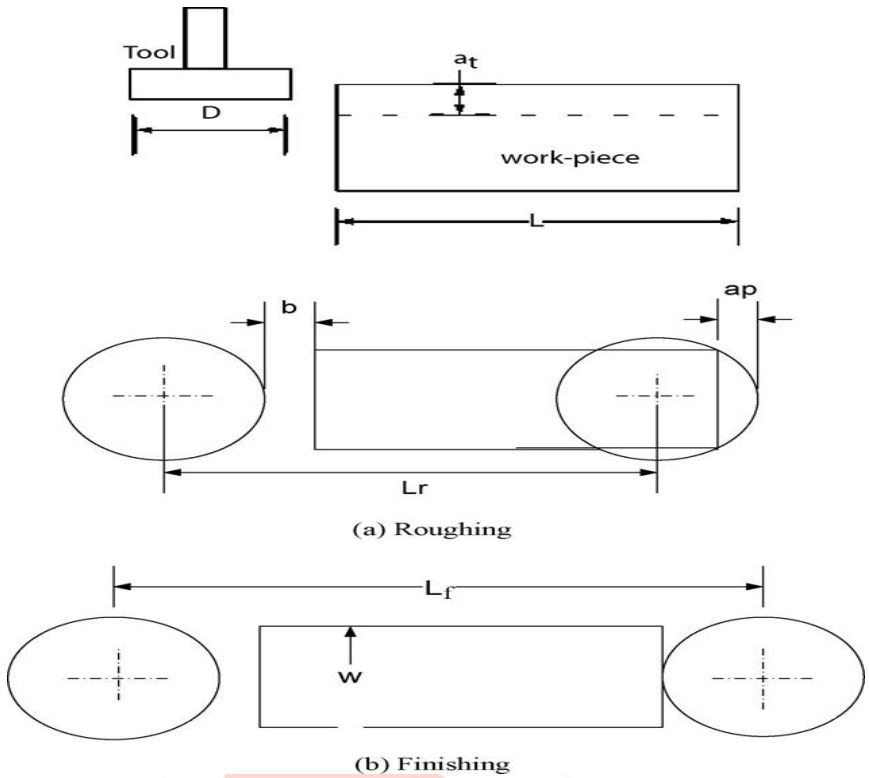

Fig-1: Schematic diagram and face-milling operation.

Objective Function
The cost of single pass U is given by

$$U = k_0 t_m + \left(k_t z\right)\frac{t_m}{T_R} + k_0 t_p + k_0\left(Lh_1 + h_2\right)$$

Where t_m is the machining expressed as $t_m = \dfrac{L_t}{zsN}$

In above equation, the length of cutter-travel, L_t is depending on whether the rough milling or finish milling is followed, *z* is the number of teeth on the cutter and *s* is the feed. The first term in above equation of cost of single pass is referred to as the machining cost, and the second term is related to the tool cost. The third and the fourth terms represent the cost of tool exchange and the cost involved in return and tool advance/retract, respectively.

Constraints
The equation of the cost of single pass U is subjected to following constraints.

1. **Tool-life (T)**
   Equation of tool life is taken from, Typical Examples and Problems in Metal Cutting and Tool Design. The tool life in face milling is expressed as:

$$T^m = \frac{c_v k_v}{v a^{x_v} s^{y_v}} \frac{D^{q_v}}{w^{t_v} z^{p_v}}$$

   where *V* is the cutting speed and *a* is the depth of cut. *D*, w and *z* are the diameter of the cutter, width of work-piece and number of teeth, respectively q_v, t_v and p_v are constant terms.

2. **Available speed (V)**
   Optimum cutting speed should be lay within the permissible range of the machine.

$$V_{\min} \le V \le V_{\max}$$

   Where *V*min and *V* max= π *DNmax* /1000 are minimum and maximum cutting speed, respectively and *N* is the spindle speed.

3. **Depth of cut (a)**

Depth of cut has to be within the specified range.

$$a_{\min} \le a \le a_{\max}$$

4. **Feed rate (s)**
The constraint on the feed is expressed as:

$$s_{\min} \le s \le s_{\max}$$

The maximum surface finish should be smaller than or equal to the required surface finish under the existing machining conditions. The surface finish (*R*a) in face-milling is given by

$R_a = \dfrac{0.0321(s)^2}{r_e}$, where r_e is the nose-radius of the cutting-edge. And taken from Fundamentals of Metal Machining and Machine Tools. Combining above both equation, the following result are obtaining:

$$s_{\min} \le s \le \min\left(s_{\max}, \left(\frac{r_e R_a}{0.0321} \right)^2 \right)$$

5. **Cutting force (F)**
Equation of cutting force is taken from, Typical Examples and Problems in Metal Cutting and Tool Design. The cutting force (*F*) must not be greater than a certain maximum value (F) given by the strength and stability of the machine and the cutting tool. The peripheral cutting force is given by

$$F_Z = C_F a^{x_F} s^{y_F} \left[\frac{B^{t_F} Z^{P_f}}{D^{q_F} n^{w_F}} \right] K_F$$

In the above equation, the effect of rotational frequency of the spindle (n_s)is ignored (w_f =) C_F and K_F are constants with regard to the tool and work-piece material.

6. **Cutting power(P)**
Power required for the cutting operation should not exceed the effective power transmitted to cutting point by the machine tool:

$$P_m \ge \frac{P_c}{n}$$

where P_m and P_c are the nominal motor power and cutting power, respectively, and n is the overall efficiency of machine tool. In milling process, mean value of power is given as

$$P_m \ge \frac{F_z V}{6120}$$

Where F_z is the mean peripheral cutting force.

III. EXPERIMENTAL WORK

In this study the Process parameter of milling process vessel optimized for minimizing the production cost by applying Harmony Search Algorithm. For this study the milling process problem and data are taken from industry and it is a real problem of the industry.

Material selection

Work Piece of GFRP with Length of 150 mm, Width 45 and thickness of 15 mm has been selected for the experimental work. The reason behind the selection is, GFRP are increasingly being used for different engineering applications because of their superior qualitative advantages include high ratio of strength to weight , high fracture strength and toughness , excellent thermal and corrosion resistance.

For machining of GFRP and advanced materials requiring high precision, complex shapes and high surface finish, selection of tool to be widely processed and applicable in manufacturing industries. Among the various metallic and non metallic Tool, S.S, Carbide steel, and Tungsten carbide have been selected as a tool with diameter of 50 mm With No of 4 Tooth.

Specification Of vertical machine center

DNM 500 vmc machine used to take experiments, machine specification are as follows:

Table-1: Machine specification**.**

Maker.	Doosan infracore
Model.	DNM 500
Table size.	1200 X 540 (mm)
X,Y,Z Travel.	1020,540,510 (mm)
Maximum Tool Diameter.	160 (mm)
Tool Shank.	BT40
Maximum work-piece weight.	500 (kg)
Maximum spindle speed.	8000 (rpm)
Maximum cutting feed(X,Y,Z).	10,10,10 (m/min)
Maximum rapid feed rate(X,Y,Z)	30,30,30(m/min)
No of tools	30
Spindle power.	12 (kw)
Machine weight.	7000 (kg)
Machine size.	4 X 2.5 (m)

Mathematical Description

Table-2: Nomenclature and Numerical data for the face milling operation

[A] Milling cost and constraints		
Overhead cost	k_o (Rs/min)	5
Cost of cutting edge	k_t (Rs/cut.edge)	160
Tool-exchange time	t_e (min/cut edge)	3
Preparation time	t_p (min/piece)	2
Tool Return time	h_1 (min/mm)	5 x 10^{-4}
Tool advance return time	h_2 (min)	3
Depth of cut	a_{min} (mm)	1
	a_{max} (mm)	4
Feed (x_1)	s_{min} (mm/tooth)	0.1
	s_{max} (mm/tooth)	0.6
Cutting speed (x_2)	V_{min} (m/min)	50
	V_{max} (m/min)	300
Tool replacement life	T_R (min)	180
Surface roughness(x_5)	R_a (rough) (µm)	10
	R_a (finish)(µm)	3
Force (x_3)	F_{max} (KN)	10
Power (x_4)	P_{max} (KW)	12
[B]. constant and exponents in face milling		
Equation	constant/exponents	
Tool-life	$C_v = 445, m = 0.32, x_{v=} 0.15, y_v = 0.35, p_v = 0, q_v = 0.2, t_v = 0.2, K_v = 1.0$	
Force	$C_F = 534.6, x_F = 0.15, y_F = 0.74, t_F = 1, w_F = 0, q_F = 1.0, p_F = 1.0, k_F = 1.0$	

IV. OPTIMIZATION METHODOLOGY

The optimization problem has four variables including number of passes and the corresponding speeds, feed and depth of cut for each pass. here result obtained for single rough pass from depth of cut 1 mm to 4 mm and for single finish pass from depth of cut 1 mm to 2 mm using harmony search algorithm as well as Genetic algorithm. The program for harmony search algorithm is developed in Matlab 7.8.0.347 and genetic algorithm is applied in the same software using inbuilt GA Tool.

Harmony search

The harmony search algorithm which is a meta heuristic optimization algorithm has been recently developed By Z W Geem. The HS algorithm is simple in concept, few in parameters, and easy in implementation. It has been successfully applied to various benchmark and real world problems.

Steps of harmony search algorithm are shown as flowchart in Fig. 2 .

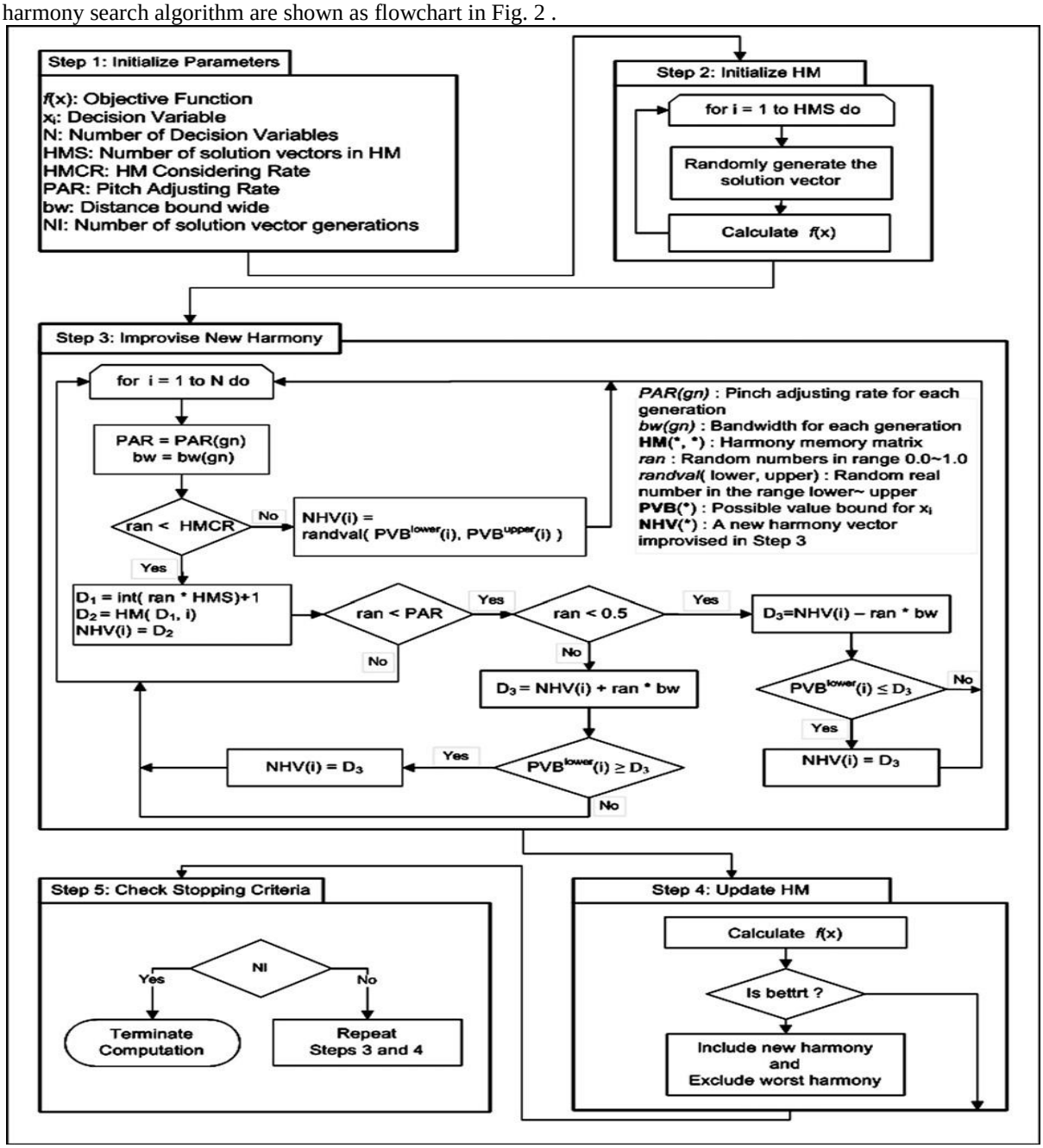

Fig-2: HSA Flow chart

Steps of HSA are as follows.

Step 1. Initialize the problem and algorithm parameters.
Step 2. Initialize the Harmony Memory (HM).
Step 3. Improvise a New Harmony memory.
Step 4. Update the Harmony memory.
Step 5. Check the stopping criterion.

V. RESULT AND DISCUSSION

A. The results are obtained using the harmony search algorithm method.

Table-3: Optimized cutting parameters and cost in face milling.

[A]. For a single rough pass

Depth of cut (a) (mm)	Feed rate $(x_1 = s)$ (mm/tooth)	Speed $(x_2 = V)$ m/min	Force(F) $(x_3 = F)$ KN	Power(P) $(x_4 = F)$ KW	Surface roughness (µm)	Cost (Rs)
1	0.599	160.552	5.879	8.125	4.034	**12.6018**
2	0.586	156.1975	6.256	10.638	5.582	**12.6183**
3	0.599	146.8595	6.256	11.244	8.916	**12.6696**
4	0.591	131.1641	6.256	9.171	6.701	**12.7768**

[B]. For a single finish pass

Depth of cut(a) (mm)	Feed rate $(x_1 = s)$ (mm/tooth	Speed $(x_2 = V)$ m/min	Force(F) $(x_3 = F)$ KN	Power(P) $(x_4 = F)$ KW	Surface roughness (µm)	Cost (Rs)
1	0.293	178.788	6.674	8.087	3	**13.3879**
2	0.294	178.767	6.162	8.127	3	**13.3996**

Result analysis

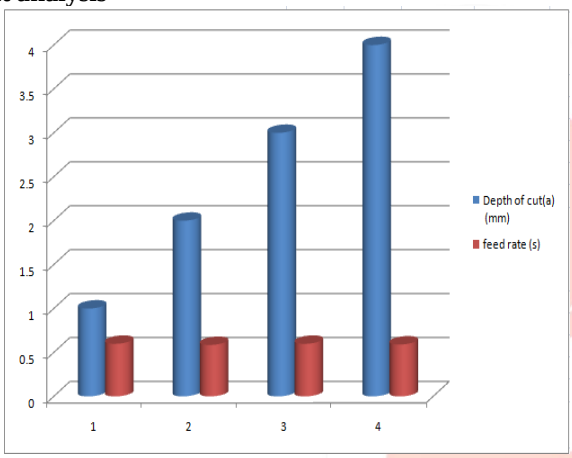

Fig- 3: Depth of cut and feed rate graph

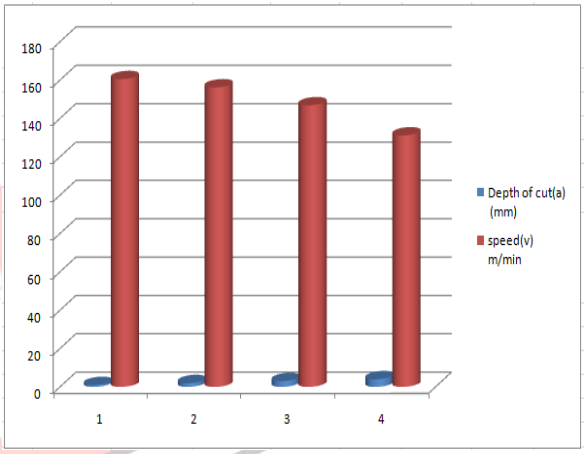

Fig-4: Depth of cut and speed grap

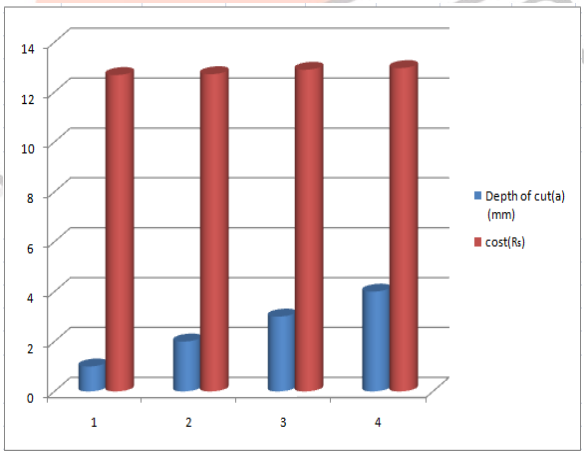

Fig-5: Depth of cut and cost graph

B. The results are obtained using the Genetic algorithm method.

Table-4: Optimized cutting parameters and cost in face milling.

[A]. For single rough pass

Depth of cut (a) (mm)	Feed rate $(x_1 = s)$ (mm/tooth)	Speed $(x_2 = V)$ (m/min)	Force(F) $(x_3 = F)$ (KN)	Power(P) $(x_4 = F)$ (KW)	Surface roughness (µm)	Cost (Rs)
1	0.434	198.633	0.865	11.978	6.059	**12.6861**
2	0.479	173.059	1.735	11.926	7.352	**12.7201**

3	0.392	174.689	2.154	11.966	4.923	**12.8982**
4	0.380	169.130	2.728	11.421	4.628	**12.9650**

[B]. For single finish pass

Depth of cut (a) (mm)	Feed rate $(x_1 = s)$ (mm/tooth)	Speed $(x_2 = V)$ m/min	Force(F) $(x_3 = F)$ KN	Power(P) $(x_4 = F)$ KW	Surface roughness (µm)	Cost (Rs)
1	0.206	257.946	0.498	11.669	3	**13.3849**
2	0.234	222.252	1.022	11.779	3	**13.4162**

Result analysis

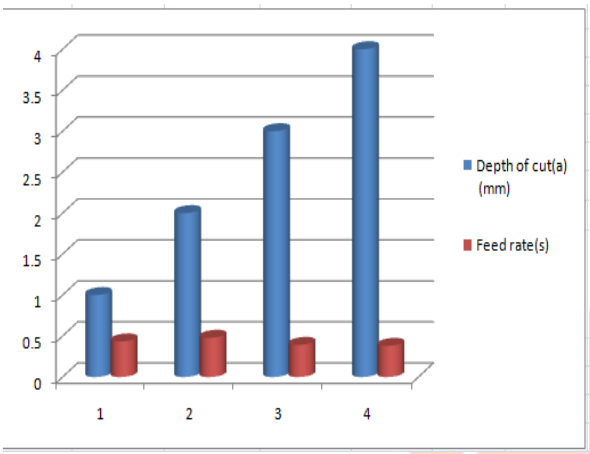

Fig-6: Depth of cut and feed rate graph

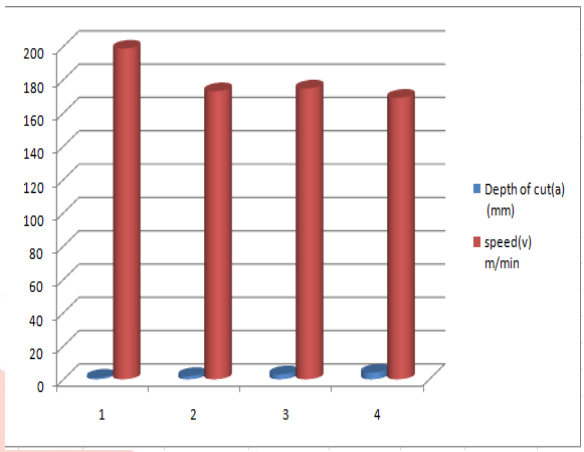

Fig-7: Depth of cut and speed graph

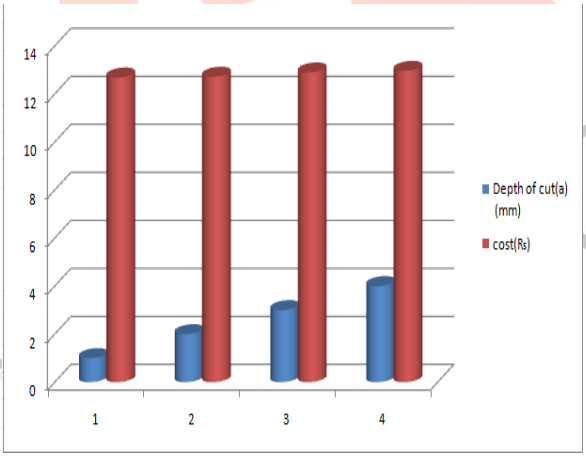

Fig-: Depth of cut and cost graph

Table-5: Comparison of HSA and GA for single rough and finish pass.

[A]. For single rough pass.

HSA		GA	
Depth of cut(a) (mm)	Cost(Rs)	Depth of cut(a) (mm)	Cost(Rs)
1	**12.6018**	1	**12.6871**
2	**12.6183**	2	**12.7201**
3	**12.6696**	3	**12.8982**
4	**12.7768**	4	**12.9650**

[B]. For single finish pass.

HSA		GA	
Depth of cut(a) (mm)	Cost(Rs)	Depth of cut(a) (mm)	Cost(Rs)
1	**13.3879**	1	**13.3849**
2	**13.3996**	2	**13.4162**

VI. CONCLUSIONS

In the current work, optimization of milling process is carried out for the face milling of GFRP material . An objective function is developed by substituting the constraints (obtained by considering the actual machining parameters)for minimizing the manufacturing cost**.**. The results shows the following points.

- Both HSA and GA has given optimum solution for each single rough pass and finished pass for surface finish as major constraint.
- Analysis has demonstrated that the HSA takes very less time compared to GA.
- The table resembles that the total cost obtained from HSA is better than GA and HSA has given optimum solution with higher accuracy and efficiency in comparison with GA.

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