Journal of Advances in Science and Technology
Vol. 13, Issue No. 01, (Special Issue) March-2017, ISSN 2230-9659

Process Parameter analysis of Plasma ARC Cutting for Surface Roughness and Material Removal Rate with the Help of Analysis of Variance Technique

Ashish P. Mahajan[1]*, Digvijay Patil[2], N. H. Deshpande[3]

[1]P.G.Scholar (Mechanical Engineering) GCE,

[2]Business Development Manager, Viraj Engineering Satara MIDC

[3]Adjunct Professor, GCE, Karad, Maharashtra, India

Abstract – This research work focuses on analyzing the process parameters of Plasma Arc Cutting of stainless steel (SS304) for surface roughness and material removal rate. The process parameters taken for this research work are torch height, arc current, arc voltage and cutting speed while response variables are material removal rate (MRR) and surface roughness. Analysis of process parameters is carried out by using ANOVA technique which is a statistical method that gives percentage contribution of each parameter on response variables. For analysis experimentation is carried out on plasma arc cutting machine in three steps. First is to make a proper experimental set up, Second step is taking pilot readings for deciding the range and level of each process parameter. Third step consist of design of orthogonal array and cutting operation according to orthogonal array. After experimentation ANOVA is carried out which gives percentage contribution of each process parameter on response variables and it is found that Arc current is most dominating parameter for surface roughness and its percentage contribution is 73.6% and cutting speed is most dominating parameter for material removal rate and its percentage contribution is 85.7%.

Keywords-Torch Height (TH), Arc Current (AC), Arc Voltage (AV), Cutting speed (CS), Analysis of Variance (ANOVA), Surface roughness (SR), Material Removal Rate (MRR)

---------------------------♦-----------------------------

INTRODUCTION

Plasma arc cutting (PAC) process is non-conventional process which is used for cutting steel and other hard materials with the help of plasma torch. Plasma is nothing but fourth state of matter which is obtained by heating the gas to an elevated temperature. Its high accuracy, finishing and ability of machining any hard material and to produce intricate shape increase its market demand.

Plasma arc cutting process cuts materials such as stainless steel, aluminum, mild steel, copper, bronze and brass, etc. For any machining, two response variables are of concern - MRR and surface roughness. From economy point of view MRR should be maximum in industrial purpose. On the other hand, surface roughness also plays a vital role as mechanical properties like fatigue behavior, creep life are dependent on surface roughness. Literatures review, modeling and analysis of plasma arc cutting processes is presented below.

Fig. 1 Plasma Arc Cutting

Milan Kumar das et al. [1] investigates effect and parametric optimization of process parameters for PAC of EN 31 Steel. They have performed ANOVA for finding the percentage contribution of each process parameter on response variable. It is found that gas pressure significantly affects responses. Ismail et al. [2] conducted an experiment using Taguchi method to optimize the process parameters in plasma arc surface hardening and found that arc current and carbon contents are recognized as most significant factors affecting the hardened depth. R. Bhuvenesh et al. [3] reported the effect on surface roughness and MRR while conducting an experiment on manual plasma arc cutting machine. They performed ANOVA for determining the most influencing parameter on response variables and Taguchi analysis for obtaining optimum condition of input parameters for response variables. Joseph C Chen et al. [4] used Taguchi design of experimentation to optimize the roundness of the hole made by aging plasma cutting machine. The response variables in this experimentation are bevel magnitude and smallest diameter deviation of the hole. Taguchi gave optimal combination (small tip size, feed rate 93 in/min, arc voltage 100V, arc current 63 A). Vinay Kumar et al. [5] explains the parametric effect on kerf and power consumed in plasma arc machine. The input variables, viz. cutting speed, arc voltage and arc current have greater influence on kerf and power. Mean response and S/N ratio gives optimum values during experimentation. Mirosalv Radovanovic et al. [6] presented an approach to develop a mathematical model for plasma arc cutting using Artificial Neural Network (ANN). In ANN three inputs and one output variable is considered. ANN model was expressed in the form of mathematical equation by which the contour plot of surface roughness was generated. Using these plots one can select machining conditions which correspond to cutting regions with minimum surface roughness.

EXPERIMENTAL WORK

To analyze the process parameters in plasma arc cutting, four cutting parameters and two response variables are considered, which are listed in following table 1.

Table I Process and response variables

Process parameters	Response Variables
Torch height (mm)	Surface roughness (R_a)
Arc voltage (Volt)	MRR (gm/sec)
Arc current (Amp)	
Cutting speed (mm/min)	

There are fixed variables used in plasma arc cutting experimentation and those are:

Table II Fixed variables

Sr. No.	Fixed Variables
1	Work m/t stainless steel (AISI 304)
2	Sample dimension (100x50x4) mm

For performing the analysis of variance on different process parameters, experimental work is carried out. This experimental design is divided into three steps and these are

A) Design and perform the experiment for pilot readings.

B) Decide the level of each parameter from pilot experimentation.

C) Design and perform the orthogonal array.

After completing these three steps, Taguchi technique and analysis of variance is done to find out the percentage contribution of each parameter on response variables. One by one illustration of above three steps is as follows

A. DOE for pilot experimentation

It was decided to conduct the pilot study for plasma arc cutting. The conventional method of variation of one parameter at a time has been used to study the effect on surface roughness and MRR with respect to cutting parameters. While performing the experimentation it is observed that surface roughness values have varying relationship with respect to process parameters, hence to obtain higher MRR and lower surface roughness it is desirable to keep process parameters at suitable level and this will be achieved by concept of normalization.

$$X_i^* = \frac{Max\ X_i^0(K) - X_i^0(K)}{Max\ X_i^0(K) - Min X_i^0(K)} \ldots\ldots\ldots\ldots 1$$

$$X_i^* = \frac{X_i^0(K) - Min\ X_i^0(K)}{Max\ X_i^0(K) - Min\ X_i^0(K)} \ldots\ldots\ldots\ldots 2$$

Equation 1 is used for lower the better characteristics, i.e. (surface roughness) and Equation 2 is used for higher the better characteristics, i.e. (MRR) to get normalized results between 0 and 1

Pilot reading for each input parameter:

NC – MEND 2017, Organized by Govt. College of Engineering, Karad, Maharashtra
In Association with The Institution of Engineers, PLC

i) Torch height (TH)

Table III Response table for normalized values and TH

AV=130V, AC=65A CS= 1300 mm/min			Norm. Values	
Torch Ht.	MRR (gm/sec)	SR(μm)	MRR (gm/sec)	SR (μm)
3	8.50	6.5	1	1
4	7.53	11	0.273	0
5	7.28	10.1	0.091	0.2
6	7.16	8.5	0	0.556

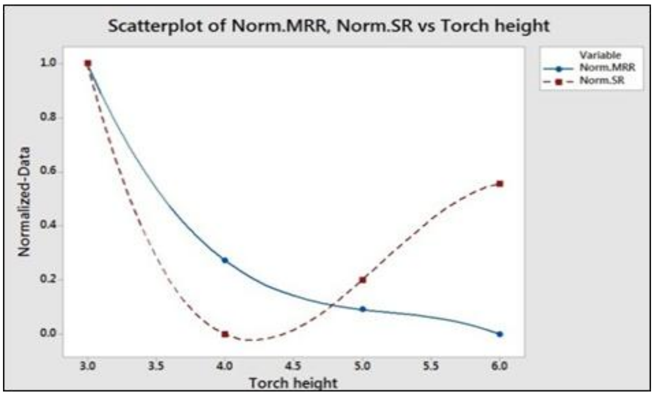

Fig 2 Scatter plotting of Norm. MRR and SR VS TH

From above graph level of torch height is selected, i.e., level 1 is 3 mm and level 2 is 5 mm. For 3 and 5 mm torch height response variables show better results.

ii) Arc Voltage (AV)

Table IV Response table for normalized values AV

TH=3 mm, AC=65 A, CS= 1300 mm/min			Norm. Values	
AV	MRR (gm/sec)	SR (μm)	MRR (gm/sec)	SR (μm)
125	7.28	9.3	0.00	0.71
130	7.53	6.5	0.22	1.00
135	8.13	16.3	0.78	0.00
140	7.89	11	0.56	0.54
145	8.25	12.5	0.89	0.39
150	8.38	8.2	1.00	0.83

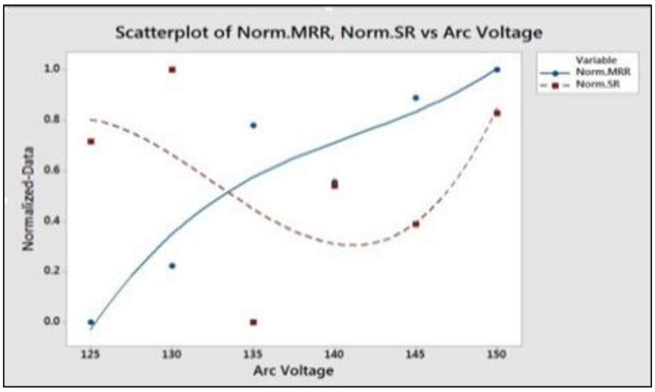

Fig 3 Scatter plotting of Norm. MRR and SR VS AV

From above graph levels of arc voltage are selected i.e., level 1: 140V, level 2: 145V, level 3: 150V. Above selected level for arc voltage gives better results for MRR and surface roughness both**.**

iii) Arc current (AC)

Table V Response table for normalized values and AC

TH=3 mm, AV=130V, CS= 1300 mm/min			Norm. Values	
AC	MRR (gm/sec)	SR (μm)	MRR (gm/sec)	SR (μm)
60	7.28	12	0.00	1.00
65	7.65	20.6	0.30	0.00
70	8.01	15	0.60	0.65
75	8.13	19	0.70	0.19
80	8.50	14	1.00	0.77

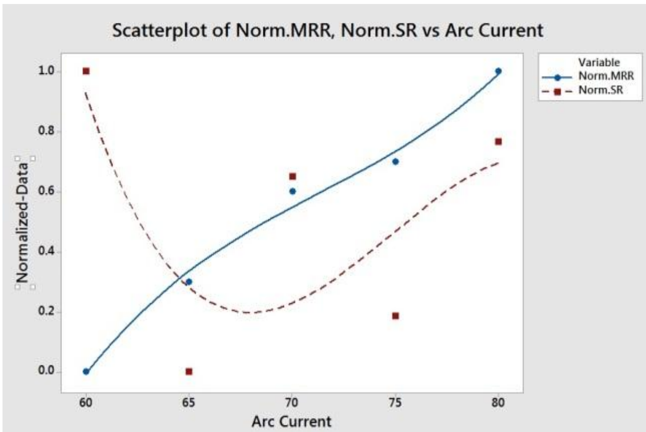

Fig 4 Scatter plotting of Norm. MRR and SR VS AC

From above graph levels of arc current are selected i.e., level 1: 70A, level 2: 75A, and level 3: 80A. This level gives better results for roughness and material removal rate.

iv) Cutting speed (CS)

Table VI Response table for normalized values and CS

AC=65Amp, AV=130V, CS= 1300 mm/min			Norm. Values	
CS	MRR (gm/sec)	SR (µm)	MRR (gm/sec)	SR (µm)
1200	7.17	7.5	0.00	0.91
1300	7.65	6.5	0.13	1.00
1400	8.37	17.7	0.33	0.00
1500	9.38	13.2	0.61	0.40
1600	10.01	15	0.78	0.24
1700	10.79	13.8	1.00	0.35

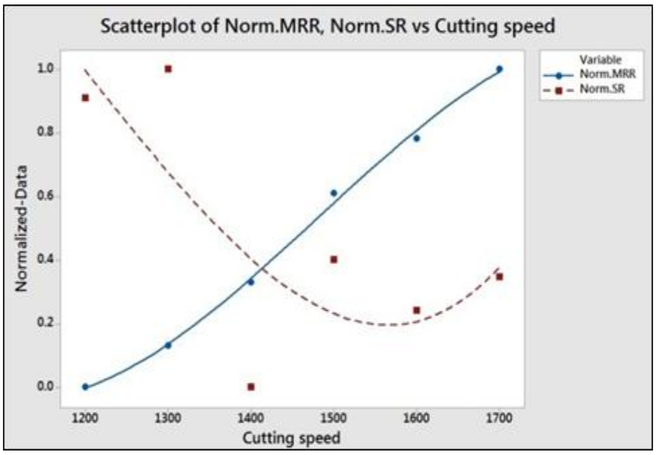

Fig 5 Scatter plotting of Norm. MRR and SR VS CS

From above graph, levels of cutting speed are selected i.e., level 1: 1500mm/min, level 2: 1600 mm/min, level 3: 1700 mm/min. These levels show better results.

TH=3 mm, AV=130V, CS= 1300 mm/min			Norm. Values	
AC	MRR (gm/sec)	SR (µm)	MRR (gm/sec)	SR (µm)
60	7.28	12	0.00	1.00
65	7.65	20.6	0.30	0.00
70	8.01	15	0.60	0.65
75	8.13	19	0.70	0.19
80	8.50	14	1.00	0.77

B. Summary Table: Level selection

Following table shows the parameter level selection and their respective values for further experimentation.

Table VII Summary table

Factors / Levels	TH (mm)	AV (Volt)	AC (A)	CS (mm/min)
1	3	140	70	1500
2	5	145	75	1600
3	-	150	80	1700

C. Design and perform orthogonal array

Considering the levels of respective process parameters, an orthogonal array is generated by using software package Mini Tab-17. Orthogonal array gives best combinations of levels to perform further experimentation. The orthogonal array is as follows.

Table VIII L18 Orthogonal Array

Sr. No	Torch Height (mm)	Arc Voltage (Volt)	Arc Current (A)	Cutting Speed (mm/min)
1	3	140	70	1500
2	3	140	75	1600
3	3	140	80	1700
4	3	145	70	1500
5	3	145	75	1600
6	3	145	80	1700
7	3	150	70	1600
8	3	150	75	1700
9	3	150	80	1500
10	5	140	70	1700
11	5	140	75	1500
12	5	140	80	1600
13	5	145	70	1600
14	5	145	75	1700
15	5	145	80	1500
16	5	150	70	1700
17	5	150	75	1500
18	5	150	80	1600

The above table describes 18 possible experiments by which we come to know that out of 18 combinations one combination is best used for cutting stainless steel of 4 mm thickness.

TAGUCHI ANALYSIS

The experimental design proposed by Taguchi involves orthogonal array which organizes the parameters which affect the processes and levels at which they should be varied. Taguchi method allows for the collection of necessary data to determine which factor has most effect on product quality with minimum amount of experimentation, thus saving time and resources.

Main Effect plots

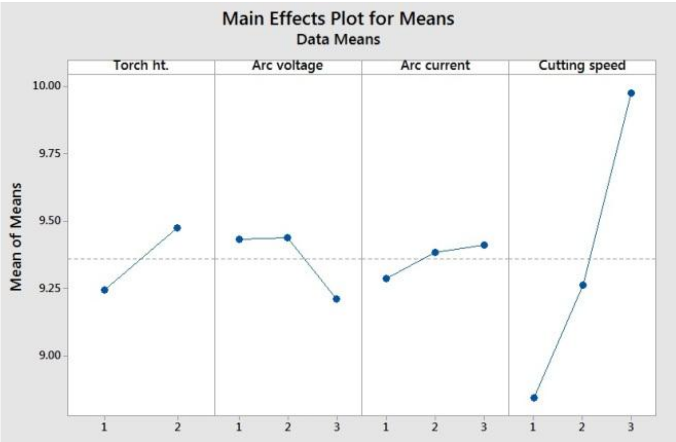

Fig 6 Main Effect plot for Material Removal Rate data means

From above graph, it can be concluded that cutting speed has larger slope than other process parameters, it means that cutting speed is more dominating parameter.

Table IX Response table for means of MRR

Level	Torch height	Arc voltage	Arc current	Cutting speed
1	9.25	9.44	9.29	8.85
2	9.48	9.44	9.39	9.26
3	-	9.21	9.41	9.98
Delta	0.230	0.23	0.12	1.13
Rank	2	3	4	1

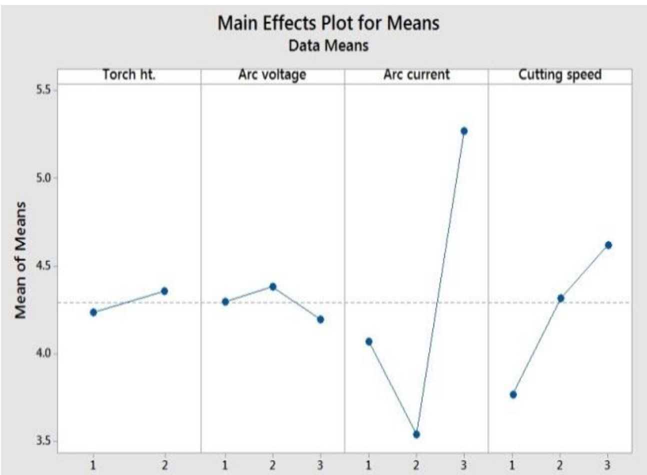

Fig 7 Main Effect plot for surface roughness data means

Table X Response table for means of SR

Level	Torch Height	Arc Voltage	Arc Current	Cutting Speed
1	4.24	4.29	4.07	3.77
2	4.36	4.38	3.54	4.38
3	-	4.19	5.27	4.62
Delta	0.12	0.18	1.73	0.85
Rank	4	3	1	2

From above table rank of arc current is 1 and from graph arc current has more slope so the arc current is most dominating parameter in case of surface roughness.

ANALYSIS OF VARIANCE (ANOVA)

As the ANOVA is a statistical method which is used to find the percentage contribution of each process parameter on response variables, so ANOVA is used in this research work to find dominating parameter and its percentage contribution for MRR and surface roughness.

Table XI ANOVA for MRR

Source	DF	SS	MS	F-value	% contribution
TH	1	0.12	0.122	9.60	2.70
AV	2	0.28	0.141	11.02	6.22
AC	2	0.11	0.056	4.39	2.46
CS	2	3.89	1.949	151.2	85.67
Error	9	0.11	0.012	-	2.53
Total	16	4.55	-	-	100

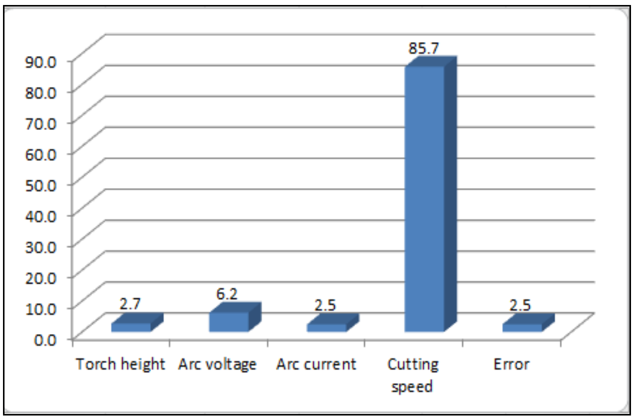

Fig 8 Percentage contribution of process parameters for MRR

From table XI, percentage contribution of cutting speed on material removal rate is 85.67% followed by arc voltage, torch height and arc current. In above table, F ratio is not required for error and total because F ratio is basically used for input process parameters to identify percentage contribution of each process parameter for various response variables.

Table XII ANOVA for SR

Source	DF	SS	MS	F-value	% contribution
T.H	1	0.024	0.0238	0.14	0.2
A.V	2	0.536	0.2677	1.63	4.8
A.C	2	8.159	4.0796	24.82	73.6
C.S	2	1.248	0.6239	3.80	11.3
Error	7	1.151	0.1644	-	10.4
Total	14	11.08	-	-	100

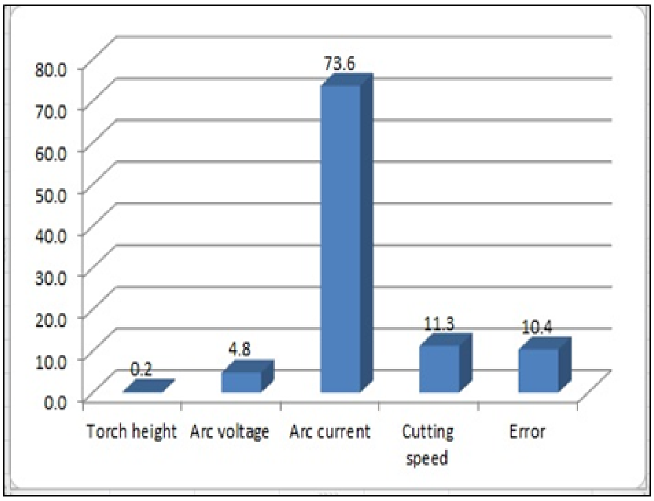

Fig 9 Percentage contribution of process parameters for SR

From above table and graph it can be concluded that Arc Current is most dominating parameter and its percentage contribution on surface roughness is more i.e., 73.6% followed by cutting speed, arc voltage and torch height.

CONCLUSION

This research work is used to find the most influencing parameter in plasma arc cutting for surface roughness (SR) and material removal rate (MRR),during experimentation and analysis it is found that for material removal rate, the cutting speed is most influencing parameter and its percentage contribution is 85.7% and for surface roughness, arc current is most influencing parameter and its percentage contribution is 73.6%. Taguchi and ANOVA is the best method of analysis which gives optimum results with minimum amount of experimentation.

ACKNOWLEDGMENT

I wish to thank Viraj Engineering Pvt.Ltd MIDC Satara for their constant support and providing facility to do experimentation on plasma arc cutting machine. I wish to express my sincere appreciation to my project guide Dr. N.H. Deshpande, a decent and disciplined personality constructive criticism and fruitful suggestions, throughout the course of my studies. I would also like to thank Dr. S.S.Mohite; Head of Mechanical Engineering Department that have always been prepared to offer me help at any time, in spite of having busy schedule. Finally I would like to thank R & D department for financial support.

REFERENCES

[1] Milan Das Kumar, Kaushik Kumar, Tapan Kr. Barman and PrasantaSahoo, "Optimization of process parameters in Plasma Arc Cutting of EN31 Steel based on MRR and multiple Roughness characteristics using Gray Relational Analysis" International conference on advance in manufacturing and Materials Engineering, AMME 2014 , Vol.5, 2014 ,pp. 1550-1559.

[2] Milan Das Kumar, Kaushik Kumar, Tapan Kr. Barman and PrasantaSahoo, "Optimization of MRR and Surface Roughness in PAC of EN 31 steel using Weighted principal component analysis"2nd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2014, Vol. 14, 2014, pp. 211-218

[3] M.I.S Ismail and Z Taha "Experimental Design and Performance Analysis in Plasma Arc Surface Hardening" International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, Vol. 05, 2011, pp. 708-714

[4] R. Bhuvenesh, M.H. Norizaman, M.S. Abdul Manan, "Surface Roughness and MRR Effect on Manual Plasma Arc Cutting Machining" International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, Vol. 06 , 2012, pp. 459-462

[5] L. J. Yang, "Plasma Surface Hardening of ASSAB 760 steel specimens with Taguchi optimization of processing parameters"

Journal of Material Process Technology, Vol. 113, 2001, pp. 521-526

[6] Joseph C. Chen Ye Li & Ronald A. Cox "Taguchi-based Six Sigma approach to optimize plasma cutting process: an industrial case study" International Journal of advance manufacturing technology , Vol. 41, 2012, pp.760-769

[7] Kulvinder Rana, Dr. Parbhakar Kaushik, Sumit Chaudhary "Optimization of plasma arc cutting by applying Taguchi Method" International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463, Vol. 2, 2013, pp.106-110

[8] Vinay Kumar. S, Prof. Dr. Ing. Georg, Dr. Rachayya Arakerimath "Taguchi Based Parametric Analysis and Optimization of Power Consumption and Kerf in Plasma Arc Machining", International Conference on Recent Advances in Mechanical Engineering In collaboration with International Journal of Engineering and Management Research (IJEMR) , 2015 ,pp. 12-16

[9] Miroslav RADOVANOVIC, Milos MADIC"Modeling the plasma arc cutting process using ann", Nonconventional Technologies Review, 2011, pp. 43-48.

[10] Bahram Asiabanpour, Durga Tejaswani Vejandla, Jesus Jimenez and Clara Novoa "Optimizing the automated plasma cutting process by design of experiments", International Journal of Rapid Manufacturing, 2009 , pp. 19-40

[11] Ali. Moarrefzadeh "Numerical Analysis of Thermal Profile in Plasma Arc Cutting", International journal of multidisciplinary sciences and engineering, vol. 2, 2011, pp. 22-25

Corresponding Author

Ashish P. Mahajan*

P.G.Scholar (Mechanical Engineering) GCE, Karad

E-Mail – ashishmahajan16@gmail.com