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Experimental investigation of Material removal rate in CNC turning using Taguchi method

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Abstract: - Machining of medium Brass alloy is very difficult. There are a number of parameters like cutting speed, feed and depth of cut etc. which must be given consideration during the machining of medium Brass alloy. This study investigates the effects of process parameters on Material Removal Rate (MRR) in turning of C34000. The single response optimization problems i.e. optimization of MRR is solved by using Taguchi method. The optimization of MRR is done using twenty seven experimental runs based on L'_{27} orthogonal array of the Taguchi method are performed to derive objective functions to be optimized within the experimental domain When the MRR is optimized alone the MRR comes out to be 8.91. The optimum levels of process parameters for simultaneous optimization of MRR have been identified. Optimal results were verified through confirmation experiments.

Keywords: Taguchi method, CNC Turning, ANOVA, MRR.

1. Introduction Brass is an alloy of copper and zinc; the proportions of zinc and copper can be varied to create a range of brasses with varying properties. In comparison, bronze is principally an alloy of copper and tin. Bronze does not necessarily contain tin, and a variety of alloys of copper, including alloys with arsenic, phosphorus, aluminum, manganese, and silicon, are commonly termed "bronze". The term is applied to a variety of brasses and the distinction is largely historical and this material is widely used for Hose fitting, watch, clock and lock parts, Bicycle spoke nipples, Plumbing valve components, screw products.

Leaded brasses are used for their high machinability and corrosion resistance. The machinability of brass is increased by the addition of lead because it acts as a microscopic chip breaker and tool lubricant. The leaded brasses are used for copper base screw machine material. The alloys have excellent machinability, good strength and corrosion resistance. Lead can be added to any brass to increase machinability[1] and provide pressure tightness by sealing the shrinkage pores. These are low, medium and high leaded brass with lead percentage up to 3.5%.The leaded brass are used for architectural hardware, general purpose screw machine parts, screws, valves and fittings, bearings and specialty fasteners. The wrought leaded brasses are designated by UNS C31200 to C38500.The microstructure of leaded brasses is similar to unleaded brasses. The microstructures of the leaded brass contain discrete lead particles primarily in the boundaries. Lead is practically insoluble in solid copper and is present in the cast and wrought materials [2, 3] as discrete particles that appear dark in structure. The microstructure of the cast lead brasses is a function of zinc content. The lower zinc containing alloys are single phase solid solution alpha dendrites, with lead particle dispersed throughout the interdendritic regions. Those with higher zinc content have a two phase structure, consisting of alpha and beta. The higher zinc containing alloys have a microstructure of all beta. The higher zinc containing alloys have a microstructure of all beta. The lead appears as discrete particles, appearing dark in the microstructure. The microstructure of wrought low zinc leaded brasses consists of twinned grains of alpha and beta phases and lead particles.

The Investigation presents the use of Taguchi method for optimizing the material removal rate in turning medium brass alloy (C34000).C34000is extensively used as a main engineering material in various industries such as screw products, plumbing equipment, and hose fitting etc. These materials are considered as easy to machining and possess superior machinability [4]. Taguchi's orthogonal arrays are highly fractional designs, used to estimate main effects using only few experimental runs. These designs are not only applicable to two level factorial experiments, but also can investigate main effects when factors have more than two levels. Designs are also available to investigate main effects for certain mixed level experiments where the factors included do not have the same number of levels. For example, a four-level full factorial design with five factors requires 1024 runs while the Taguchi orthogonal array reduces the required number of runs to 16 only.

Feng. Cang-Xue (Jack) [5] studied the impact of turning parameters on surface roughness. He studied the impact of Feed, Speed and Depth of Cut, Nose radius of tool and work material on the surface roughness of work material. He found that the feed have most significant impact on the observed surface roughness and also observed that there were strong interactions among different turning parameters.

Jafar Zare and Afsari Ahmad [6] the performance characteristics in turning operations of Df2 (1.2510) steel bars using TiN coated tools. Three cutting parameters namely, cutting speed, feed rate, and depth of cut, will be optimized with considerations of surface roughness.
The study shows that the Taguchi method is suitable to solve the stated within minimum number of trials as compared with a full factorial design.
The main objective of this study was to demonstrate a systematic procedure of using Taguchi design method in process control of turning process and to find a combination of turning parameters to achieve low material removal rate.
Experiments were designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. Using Taguchi method, Appropriate Orthogonal Array [7,8] has been chosen and experiments have been performed as per the set of experiments designed in the orthogonal array. Signal to Noise ratios are also calculated to analyze the effect of parameters more accurately.

Results of the experimentation were analyzed analytically as well as graphically using ANOVA. ANOVA has determined the percentage contribution of all factors upon each response individually.

2. Taguchi method

Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases [16, 17, 18]. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only.

Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N).

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

(I) SMALLER-THE-BETTER:

$$n = -10 \text{ Log}\left(\frac{1}{n}\sum_{i=0}^{n}\frac{1}{y2}\right)$$

(II) LARGER-THE-BETTER:

$$n = -10 \text{ Log}_{10} \text{ [mean of sum squares of reciprocal of measured data]}$$

(III) NOMINAL-THE-BEST:

$$n = 10 \text{ Log}_{10} \frac{\text{Square of means}}{\text{variance}}$$

Larger the better for minimum material removal rate and surface roughness so,

Larger the better = s/n = -10 Log_{10} [mean of sum squares of reciprocal of measured data]

Regardless of category of the performance characteristics, the lower S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the lowest S/N value. The statistical analysis of the data was performed by analysis of variance (ANOVA) [9, 10] to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

3. Design of experiment

In this study, three machining parameters were selected as control factors, and each parameter was designed to have three levels, denoted 1, 2, and 3 (Table 1). The experimental design was according to an L27 array based on Taguchi method, while using the Taguchi orthogonal array would markedly reduce the number of experiments.
A set of experiments designed using the Taguchi method was conducted to investigate the relation between the process parameters and delamination factor. DESIGN EXPERT @ 16 minitab software was used for regression and graphical analysis of the obtained data.

Table 1 Turning parameters and Levels

Symbol	Turning Parameters	Level 1	Level 2	Level 3
A	**Cutting speed, (mm/min)**	55	75	95
B	**Feed rate, (rev/min)**	0.15	0.25	0.35
C	**Depth of cut, (mm)**	0.10	0.15	0.20

4. Experimental details

Medium brass alloy (C34000) of **Ø**: 19 mm, **length**: 280 mm were used for the turning experiments in the present study. The chemical composition and mechanical and physical properties of C34000 can be seen in Tables 2 and 3, respectively. The turning tests were carried out to determine the material removal rate under various turning parameters. GC1035 coated carbide tool were used for experimental investigations.

Table 2 Chemical composition of C34000 (Medium brass alloy)

Element	Percentage
Zinc, Zn	34% max
Lead, Pb	0.9% max
Iron, Fe	0.095% max
Copper, Cu	Balance

Table 3 Mechanical and physical properties of C34000 (Medium brass alloy)

Property	Value
Density	8.47g/cc
Hardness	68HRF
Electrical Resistivity	39.9 microhm-cm
Melting Point	1630 ^{0}F
Thermal Conductivity	9.5
Modulus of Elasticity Tension	15.0
Yield Strength	410 MPa
Ultimate Tensile Strength	340 MPa
Elongation	45%
Reduction of Area	30%

5. Results and discussion

5.1 Experiment results and Taguchi analysis

In machining operation, maximizing the material removal rate (MRR) is an important criterion. Leaded brasses are used for their high machinability and corrosion resistance. The machinability of brass is increased by the addition of lead because it acts as a microscopic chip breaker and tool lubricant. The leaded brasses are used for copper base screw machine material. The alloys have excellent machinability, good strength and corrosion resistance. Lead can be added to any brass to increase machinability and provide pressure tightness by sealing the shrinkage pores. [4].

A series of turning tests was conducted to assess the influence of turning parameters on material removal rate in turning C34000. Experimental results of the material removal rate for turning of C34000 with various turning parameters are shown in Table 4. Table 4 also gives S/N ratio for material removal rate. The S/N ratios for each experiment of L27 (3^13) was [15] calculated. The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor. Table 5 shows average effect response table. Thus, by utilizing experiment results and computed values of the S/N ratios (Table 5), average effect response value and average S/N response ratios were calculated for material removal rate.

Table 4 EXPERIMENTAL RESULT AND CORRESPONDING S/N RATIO

Exp. No	CS(mm/min)	FR(mm/rev)	DOC(mm)	MRR(mm^3/min)	S/N Ratio
1	55	0.15	0.1	0.825	-1.67
2	55	0.25	0.15	1.237	1.85
3	55	0.35	0.2	1.64	4.296

4	55	0.15	0.1	1.357	2.766
5	55	0.25	0.15	2.062	6.287
6	55	0.35	0.2	2.75	8.786
7	55	0.15	0.1	1.925	5.688
8	55	0.25	0.15	2.888	9.21
9	55	0.35	0.2	3.85	11.709
10	75	0.15	0.1	1.125	1.023
11	75	0.25	0.15	1.687	4.544
12	75	0.35	0.2	2.25	7.043
13	75	0.15	0.1	1.875	5.46
14	75	0.25	0.15	2.812	8.981
15	75	0.35	0.2	3.75	11.48
16	75	0.15	0.1	2.625	8.382
17	75	0.25	0.15	3.937	11.904
18	75	0.35	0.2	5.25	14.403
19	95	0.15	0.1	1.425	3.076
20	95	0.25	0.15	2.137	6.598
21	95	0.35	0.2	2.85	9.096
22	95	0.15	0.1	2.375	7.513
23	95	0.25	0.15	3.562	11.035
24	95	0.35	0.2	4.75	13.533
25	95	0.15	0.1	3.325	10.435
26	95	0.25	0.15	4.987	13.957
27	95	0.35	0.2	6.65	16.456

Table 5 ANOVA table for Material removal rate

Variable Factors	Designation	DF	SS	V	F	P	Contribution
Cutting speed	A	2	102.29	6.542	1.239	0.354	17.67*
Feed rate	B	2	247.588	208.089	43.13	0	42.77***
Cutting speed*Feed	A*B	4	44.858	11.214	2.32	0.17	7.75
Depth of cut	C	2	164.386	8.4	4.518	0.006	28.40**
Cutting speed*DOC	A*C	4	5.958	1.49	0.31	0.862	1.029
Feed rate*DOC	B*C	4	13.697	3.424	0.71	0.614	2.36
Error		8	272.172	176.436			0.021
Total		**26**	578.777				

Where DF-degree of freedom, SS-sum of squares, V-variance, F-a statistical parameter, P-percentage and the *** & ** represents most significant and significant parameters and * as less significant.

The regression equation is [11, 12]:

S/N Ratio of MRR = - 8.51 + 0.119 CS + 30.1 FR

S = 3.22619 R-Sq = 51.4% R-Sq(adj) = 47.4% PRESS = 317.706 R-Sq(pred) = 38.22%

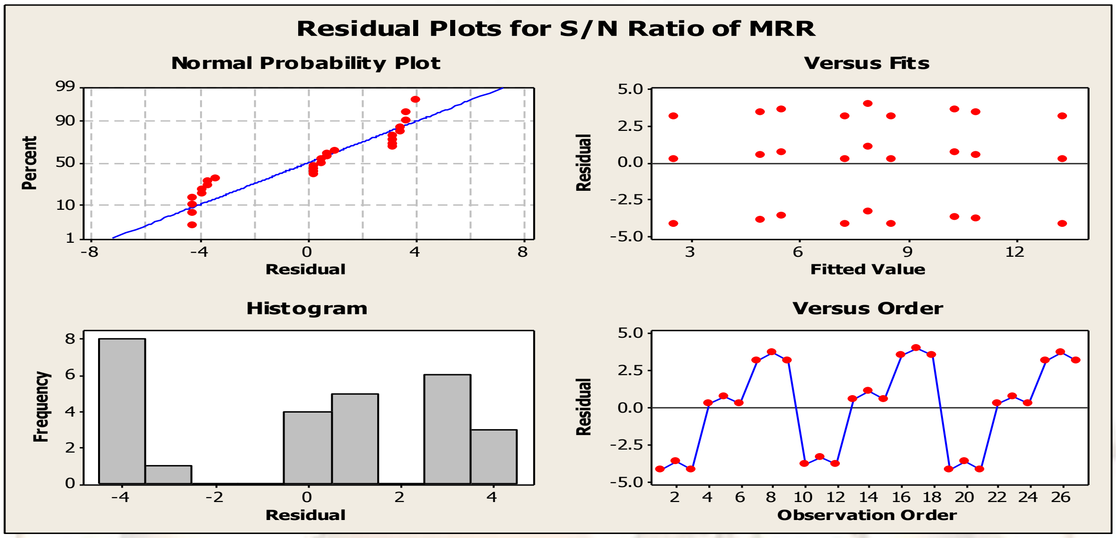

Fig 1: Residual analysis of MRR of first degree polynomial equation

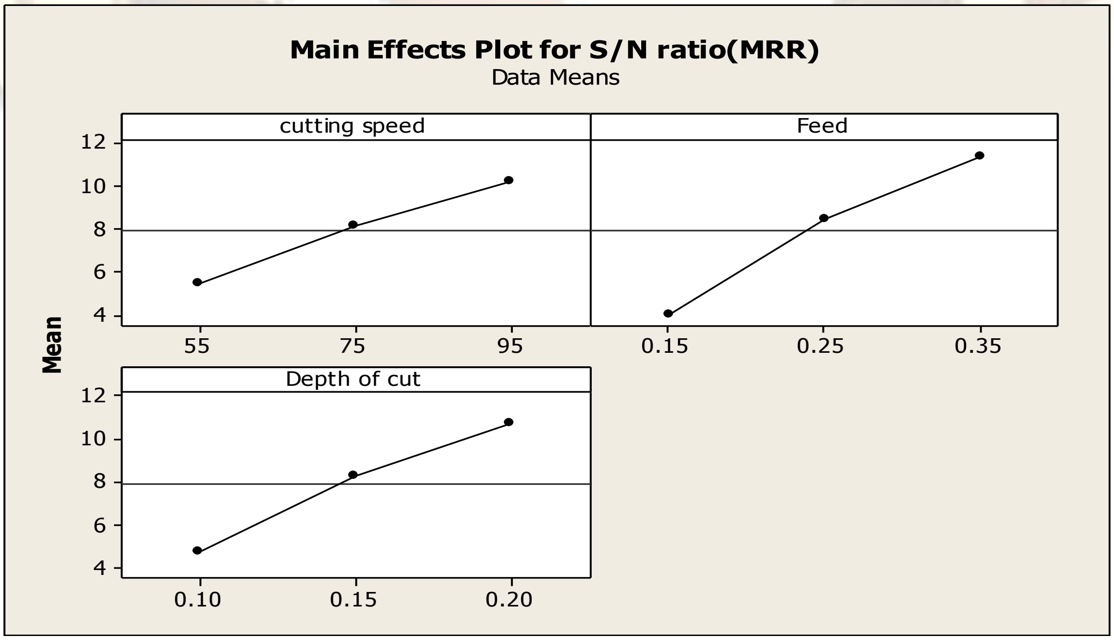

Fig 2: Effect of turning parameters on Material removal rate

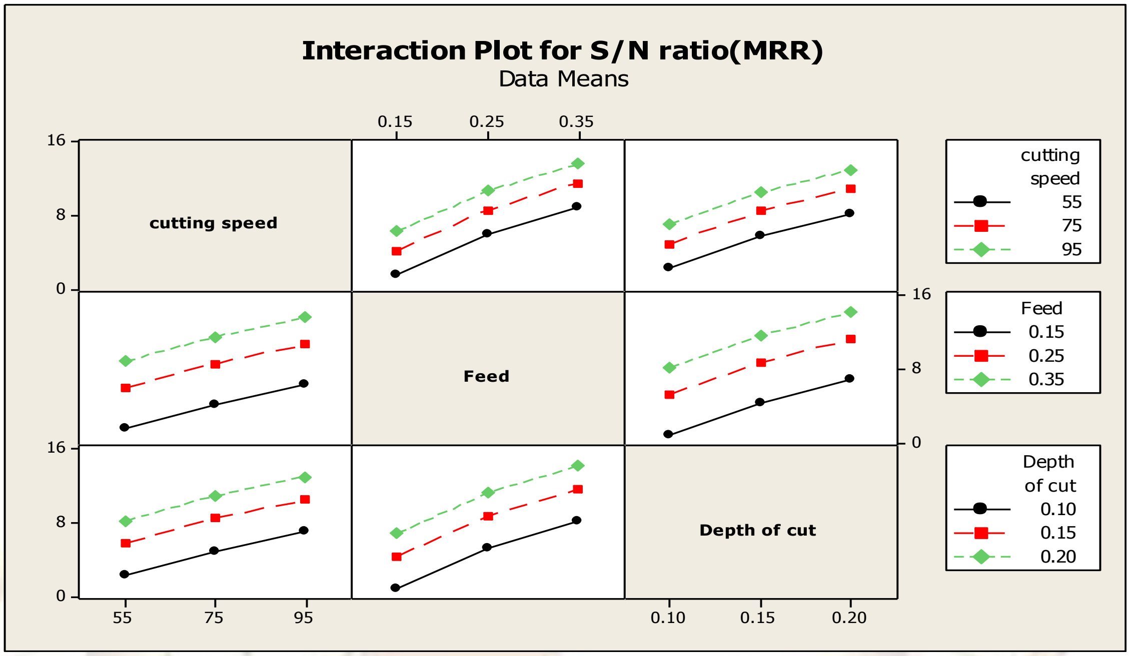

Fig 3: Interaction Plot for S/N Ratios of MRR

From the ANOVA table it is clear that maximum contribution factor is feed rate having percentage contribution up to 42.77%.After that second main Contribution is of depth of cut which means the combined effect of feed rate and depth of cut. Hence the individual ranking of these three parameters on the average value of means of Material removal rate:-

Table 6 Mean values of process parameters for material removal rate

Level	Cutting Speed (A)	Feed Rate (B)	Depth of cut (C)
1	5.78	4.12	4.93
2	8.14	8.20	8.12
3	10.04	11.85	11.24
Rank	4	1	3

5.2 Predictive Equation and Verification

The predicted value of MRR at the optimum levels [13, 14] is calculated by using the relation given as:

$$\eta = \eta m + \sum_{i=1}^{0} (\eta im - \eta m)$$

Applying this relation predicted value of MRR at the optimum conditions is obtained as:

$$\hat{\eta}_{MRR} = 8.806 + [(11.71 - 8.806) + (11.48 - 8.806) + (11.90 - 8.806)]$$

$$\hat{\eta}_{MRR} = 8.91 mm^3/min$$

The experiment is conducted at the predicted optimum conditions and the average of the response is 8.91. The error in the predicted and experimental value is only 1.2%, so good agreement between the actual and the predicted results is observed. Since the percentage error is less than 5%, it confirms excellent reproducibility of the results. The results show that using the optimal parameter setting ($A_1B_3C_2$) a higher material removal rate is achieved. Table shown below shows that optimal values of material removal rate lie between the optimal range.

Table 7 Optimum Levels of Process Parameters

Cutting Parameters	Optimal Values Of Parameters	Optimal Setting Level	Predicted Optimal Value	Optimal Value Of Mrr	Experimental Values
Cutting speed(A) Feed Rate(B) Depth of cut(C)	55mm/min 0.35mm/rev 0.2mm	$A_1B_3C_2$	8.91	$8.78 < \eta_{MRR} > 8.91$	8.78

5.2 Results

The effect of parameters i.e Cutting speed, feed rate and depth of cut and some of their interactions were evaluated using ANOVA analysis with the help of MINITAB 16 @ software. The purpose of the ANOVA was to identify the important parameters in prediction of Material removal rate. Some results consolidated from ANOVA and plots are given below:

5.2.1 Material removal rate

Feed rate is found to be the most significant factor & its contribution to material removal rate is 42.77 %. The interaction between cutting speed and feed rate is found to be significant which contributes 7.75%.The best results for Material removal rate (lower is better) would be achieved when C34000 workpiece is machined at cutting speed of 55 mm/min, depth of cut of 0.2 mm, feed rate of 0.35 mm/rev. With 95% confidence interval, the feed rate effects the material removal rate most significantly.

6. Conclusion

The present study was carried out to study the effect of input parameters on the material removal rate. The following conclusions have been drawn from the study:

1. The Material removal rate is mainly affected by cutting speed and feed rate. With the increase in cutting speed the material removal rate is increases & as the feed rate increases the material removal rate is increases.
2. From ANOVA analysis, parameters making significant effect on material removal rate feed rate, and interaction between feed rate & cutting speed were found to be significant to Material removal rate for reducing the variation.
3. The parameters considered in the experiments are optimized to attain maximum material removal rate. The best setting of input process parameters for defect free turning (maximum material removal rate) within the selected range is as follows:
   - i) Cutting speed i.e. 55m/min.
   - ii) Feed rate i.e. 0.35mm/rev.
   - iii) Depth of cut should be 0.2mm.

References

[1] Phadke M.S, "quality engineering using design of experiment, Quality control, robust design & the taguchi method". *Wadsworth & books. California*, (1988). pp 35-36.

[2] Bhattacharya Anirban and Das Santanu, "Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA" *Production Eng. Res. Devel.* (2009) 3:31–40.

[3] Rodzi Mohd. & Jaharah A.G., "Performance of Coated Carbide Tool in Green Turning of FCD 700 ductile Cast Iron", *Jordan journal of mechanical and industrial engineering*, vol. 4, (2004), pp 110-117.

[4] Singh Hari, "Optimizing Tool Life of Carbide Inserts for Turned Parts using Taguchi's Design of Experiments Approach", Proceedings of the *International MultiConference of Engineers and Computer Scientists* (2008) Vol II, 19-21.

[5] Kaladhari M. and Subbaiah K.V, "Application of Taguchi approach and Utility Concept in solving the Multi-objective Problem when turning AISI 202 Austenitic Stainless Steel", *Journal of Engineering Science and Technology Review* 4 (1) (2011) 55-61.

[6] Jafar Zare and Afsari Ahmad, "application of Taguchi method in the optimization of cutting parameters for surface roughness in turning", *Proceedings of academic journal of manufacturing engineering*, vol. 8, (2010), issue 3.

[7] Munteanu, "Application of taguchi method for cutting force in turning high density polyethylene", *academic journal of manufacturing engineering*, vol. 8, (2010), issue 3.

[8] Kolahan Farhad and Manoochehri Mohsen, "Parameters and Tool Geometry Specifications in Turning Operation of AISI 1045 Steel", *World Academy of Science, Engineering and Technology* (2011).

[9] Selvaraj D. Philip and Chandarmohan P., "optimization of surface roughness of AISI 304 austenitic stainless steel in dry turning operation using Taguchi design method", *Journal of Engineering Science and Technology* Vol. 5, No. 3 (2010) 293 - 301.

[10] Kamarudin K. and Rahim E. A., "Optimizing Surface Roughness and Flank Wear on Hard Turning Process Using Taguchi Parameter Design", *Proceedings of the World Congress on Engineering* July 2 - 4, (2007), London, U.K.

[11] Gopalsamy B.M., Mondal B. and Ghosh S., "Taguchi method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel", *Journal of Scientific and Industrial Research*, vol. 68, (2009), pp. 686-695.

[12] Kahraman, F., "The use of response surface methodology for prediction and analysis of surface roughness of AISI 4140 steel", *Materials and technology*, vol. 43, no. 5, (2009), pp. 267–270.

[13] Cayda U., "Machinability evaluation in hard turning of AISI 4340 steel with different cutting tools using statistical techniques ", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* (2010).

[14] Thamizhmanii S., Saparudin S. and Hasan S, "Analysis of Surface Roughness by Using Taguchi Method", *Achievements in Materials and Manufacturing Engineering,* (2007), Volume 20, Issue 1-2, pp. 503-505.

[15] Sahoo P., Barman T. K. and Routara B. C., "Taguchi based practical dimension modeling and optimization in CNC turning", *Advance in Production Engineering and Management,* Volume 3, (2008), pp. 205-217.

[16] Lan T.-S., Lo C. Y., Wang M.-Y. and Yen A-Y, "Multi Quality Prediction Model of CNC Turning Using Back Propagation Network", Information. Proceeding of *American society of mechanical engineers*, (2008).
[17] Palanikumar K. and Karunamoorthy L., "Optimization of Machining Parameters in Turning GFRP Composites Using a Carbide (K10) Tool Based on the Taguchi Method with Fuzzy Logics", *metals and materials International*, Vol. 12, No. 6 (2006), pp. 483~491.
[18] Dhavamani C. and Alwarsamy T., "review on optimization of machining", *international journal of academic research,* (2011), Vol. 3. No. 3. May, II Part.