International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 2 Feb 2021, pp: 604-611 www.ijaem.net ISSN: 2395-5252

Influence of Surface Roughness and Taper Angle on Wood Dust Filler Reinforcement Polymer composite in AWJM

Aniket Rajaram Patil[1], Rajeshwari Sanjay Rawal[2], Jagadish[3]
[1]*Student, National Institute of Technology, Silchar, India*
[2]*Senior Software Development Engineer, Research and Development Department, C3P Engineering Software International*
[3]*Associate Professor, Department of Mechanical Engineering, National Institute of Technology, Silchar, India.*

Submitted: 10-02-2021 Revised: 20-02-2021 Accepted: 26-02-2021

ABSTRACT: The importance of the present work is to study the influence of abrasive water jet machining (AWJM) parameters on wood dust filler based reinforcement polymer (WDFRP) composite. The parameters such as standoff distance (SoD), working pressure (WP), nozzle speed (NS), and abrasive grain size (AGS) as input while the surface roughness (SR), and a taper angle (TA) as output parameters. Experimentation is performed using Taguchi (L9) Orthogonal array and effect of AWJM parameters on the output parameters via parametric analysis. Additionally, ANOVA and multiple regression analysis are carried out to determine the most significant parameters and interdependency between the parameters. At last, verification of the experimental results through confirmatory tests.
KEYWORDS: AWJM, AGS, NS, SR, TA, WDFRP.

I. INTRODUCTION

Recently, various researchers work on machining of polymer composite because, the use of polymer composite is significant increases due to low cost, easy treating, low weight, biodegradable, and environmental friendly etc. In today's world, various polymer composites are fabricated such as ceramic matrix composites (CMC), natural fiber polymer (NFRP) composite, carbon fiber reinforced polymer (CFRP) composite, glass fiber reinforced polymer (GFRP) composite etc. From these, NFRP composite has various industrial applications such as automotive, aerospace, tool and die making, household applications etc.[1,2]. The NFRP composite fabricates from, epoxy as a matrix and natural filler as reinforced material. Various researchers fabricated the NFRP composite from varieties of natural fillers like pineapple, banana, flax, cotton, husk, bamboo, hemp, jute and wood etc.[3]. Apart from these natural fillers, the wood dust or wood filler is used in most of the cases due to renewable in nature, low cost, less abrasive, environmentally friendly, lower specific weight, and non-toxicity etc. over the other NFRP composites[4-7]. On the other side, the machining of wood dust filler reinforced polymer (WDFRP) composite is very difficult by conventional and some of the non-conventional machining (NCM) methods[8]. This is because of their relatively low sensitivity to heat damage, fiber pullout during the drilling, poor surface roughness, improper cutting, low productivity etc. Moreover, some NCM methods such as electro-discharge machining (EDM) and wire electro discharge machining (WEDM) is not applicable on WDFRP composite because of non-conductive behaviour as well as the low thermal conductivity of the composites[9]. Also, laser machine is used for machining of WDFRP composite but the result is in burning of these composites owing to their lesser thermal conductivity as shown in Figure.

Effect of laser cutting on WDFRP composites

Moreover, machining in USM is found to be difficult, due to more ductility and low hardness of the WDFRP composite. To overcome the difficulties of NCM methods for machining of WDFRP composites, the AWJM is being used in this study for machining of WDFRP composites.

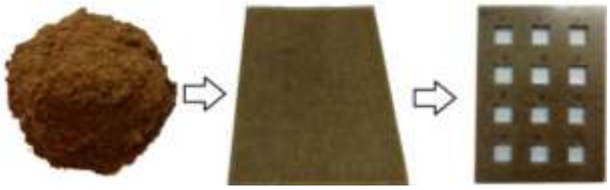
Basically, the AWJM process is a well-known machining process widely used for machining of many kinds of engineering materials such as all metals, non-metals and composites etc. Also, the machining performance of AWJM process strongly depends on the several process parameters such as SoD, WP, NS, AGS, etc. and response parameters. The suitable setting of the process parameters is necessary to obtain optimal results. Therefore, the study of parametric effect is essential to inspect the impact of each of the input parameters on the response during machining8.

The aim of this paper is to study the effect of input parameters of AWJM on WDFBP composite. The Taguchi (L9-orthogonal array) is used for the formulation of experimental design while the influence of AWJM parameters on the responses via parametric analysis. Further, interactive study and multiple regression analysis are performed to determine the interrelationship between the input and output parameters of AWJM process. Finally, the obtained results are verified by the experimental results through confirmatory analysis.

II. MATERIAL AND METHOD

Specimen Preparation

In this study, SWD is used as reinforcement material with particle size 400 µm and density 0.779 gm/cc as shown in Fig 2. The main constituents of the sundi wood are cellulose, glucomannan, xylem, and lignin [3]. During the specimen preparation, the Epoxy (Araldite LY 556) is used as a matrix material with density 1.26 gm/cc and corresponding hardener (HY 951) are mixed in the ratio of 10:8 by weight. After that, the mixer is mechanically stirred and gradually poured into the vacuum glass chamber and allowed to cure for 24-48 hours at room temperature. The specimen with a size of 180 mm × 140 mm × 6 mm is taken for the actual machining.



(a) Sundi wood dust (b) Prepared specimen (c) Machined specimen

III. EXPERIMENTAL TECHNIQUE

The Taguchi (L9) Orthogonal array was used for the formulation of experimental design as shown in Table 2. There are many standard orthogonal arrays available, each of these arrays is meant for a specific number of independent design variables and their levels[3]. The present work contains two different dependent variables such as SR, and TA and four independent variables such as SoD, WP, NS, and AGS with three levels. In order to select the appropriate OA for selected AWJM parameters, the minimum no. of experiments essential for experimentation is needed to be calculated. Based on the Taguchi design, the required number of experiments for four parameters with three levels is obtained to be 9 [1+4(3-1) =9]. Thus, at least 9 experiments is required to be performed for AWJM process parameters. Therefore, present work used L9 OA for the experimentation. The actual machining is carried out in CNC Water Jet Cutting Machine manufactured by DARDI International Corporation, China as sheen in Fig.3. The designed pressure of 3800 bar, discharge rate as 2.31 l/min and an orifice diameter of 0.25 mm were taken during the experimentation[10]. Abrasive material of type Garnet with of size 70, 80, and 90 mesh, mixed with a distilled water at room temperature were used as an abrasive slurry. Throughout the experiments, the voltage of 300 V, a current of 20 A and nozzle angle of 900 were input to the AWJ machine. The work specimen on size 180 mm × 140 mm × 6 mm was taken for machining. In this work input parameter such as SoD, WP, NS, and AGS with their levels as depicted in (Table 1) are used**.** During the experiment, a square of 20 mm × 20 mm of the hole was cut. Each experimentwas performed 3 times and calculate their average of SR, and TA for the analysis as shown in (Table 2)[14].

Input parameters	**Symbol**	**Units**	**Level 1**	**Level 2**	**Level 3**
Stand of Distance	SoD	Mm	1	2	3

Work Pressure	WP	MPa	100	125	150
Nozzle Speed	NS	mm/min	100	200	300
Abrasive Grain Size	AGS	Mesh	70	80	90

Input parameters and their levels for AWJM process. AWJM SETUP

After machining, responses such as surface roughness (SR) is quantified using Surface Profilometer (Make: Tokyo Seimitsu co. Ltd. Model: Hanhysurf E-35B) while taper angle (TA) for each of the setting were calculated using the following expression:

$$TA(\theta) = \tan^{-1}\frac{T_K - B_K}{2 \times T_W} \quad (1)$$

Where TK and BK represent top kerf and bottom kerf; TW is the thickness of work piece, and TA is the taper angle in degree15. The results of experimental design are tabulated in Table .

Ex. No.	Input parameters				Output parameters	
	SoD (mm)	WP (MPa)	NS (mm/min)	AGS (mesh)	SR (µm)	TA (degree.)
1	1	100	100	70	0.150	0.189
2	1	125	200	80	0.143	0.406
3	1	150	300	90	0.172	0.301
4	2	100	200	90	0.130	0.426
5	2	125	300	70	0.135	0.556
6	2	150	100	80	0.185	0.279
7	3	100	300	80	0.160	0.118
8	3	125	100	90	0.102	0.119
9	3	150	200	70	0.178	0.234

Experimental results of AWJM process

IV. RESULTS AND DISCUSSION

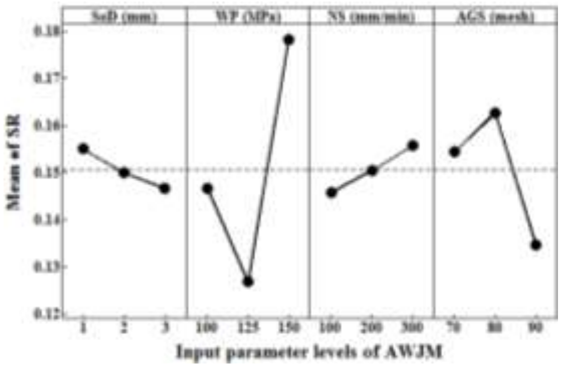
Parametric investigation

I. Influence of input parameters on SR

The effect of input parameters on surface roughness (SR) of WDFRP composite is studied using main effect plot19 as shown in Fig.(4). The graph shows that the SR is drastically decreased when SoD is decreased from 1 mm to 3 mm. This is because at higher SoD the kinetic energy is more and it helps to remove the material smoothly14 as can be seen in Fig.(4). Whereas, exactly opposite effect is seen in the case of NS because increase in NS (i.e. from 100 mm/min to 300 mm/min) value of SR is also increased (i.e. 0.145 µm to 0.155 µm). This is due to the reason that kinetic energy of the abrasive particle is higher at higher nozzle speed and it helps to remove more material and in result rough surface is obtained15. In the case of WP and

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 2 Feb 2021, pp: 604-611 www.ijaem.net ISSN: 2395-5252

AGS exactly opposite behaviour is obtained. In the case of WP, the SR value is decreased from (0.1466 µm to 0.1266 µm) when WP is increasing from 100 MPa to 125 MPa. Thereafter, a sudden increase of SR value (i.e. 0.1266 µm to 0.1783 µm) when WP is increasing (i.e. 125 MPa to 150 MPa) as can be seen in Fig.(4). This is due to the fact that, at lower WP, the penetration of abrasive particle is less and not able to remove more material. In the graph, as the AGS increased from 70 mesh to 80 mesh the SR value is slightly increased from 0.154 µm to 0.162 µmand then SR value is observed to be drastically decreased (i.e. from 0.162 µm to 0.134 µm) from 80 mesh to 90 mesh grain size. This is because the larger grain size is a help to remove material smoothly and in result in decreased SR value. Based on this analysis, the optimal combination of input parameters for lower SR is SoD (3 mm, level 3), WP (125 MPa, level 2), NS (100 mm/min, level 1) and AGS (90 mesh, level 3).

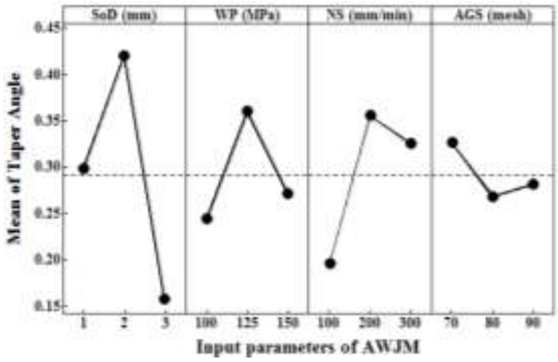


Mean of SR for different input levels

II. Influence of input parameters on TA

TA is defined as a slot having a top area wider than the bottom area or vice versa. It is produced when cutting through AWJM[20] and measured by using Eq. (2). The mean effective plot of TA is shown in Figure. It is seen that parameter, TA is increased when SoD is increased from 1 mm to 2 mm and after that TA is suddenly decreased from 2 mm to 3 mm. this is because, at higher SoD, erosion of abrasive particles at the inner wall of the WDFRP composite is straight, results in lesser TA[21]. On the other hand, similar behavior is found for TA in the case of WP and NS as shown in Figure. The sudden increase of TA value (i.e. 0.244 to 0.360 deg. and 0.195 to 0.355 deg) when the WP and NS are increased from 100 MPa to 125 MPa and 100 mm/min to 200 mm/min respectively. Thereafter, drastic reduction of TA value (i.e. 0.360 to 0.271 deg. and 0.355 to 0.325 deg.) is found for higher WP and NS as can be seen

In Figure This happens because, higher WP and NS made the abrasive particles to cut composites faster and no diversion of the abrasive particles during the cutting, therefore, lesser TA is observed in the case of WDFRP composite machining[21]. In the case of AGS, the response TA value (i.e. 0.326 deg. to 0.268 deg.) is decreased from grain size 70 mesh to 80 mesh and slightly increased from (0.268 deg. to 0.281 deg.) when the AGS from (i.e. 80 mesh to 90 mesh). This implies because, increase of AGS, higher material removal rate when abrasive are bombarding on the workpiece, this results in lesser TA as similar behavior is seen in Figure.. However, further increase of AGS from 80 mesh to 90 mesh, the value of TA is found to be slightly increased because the higher grain size covers alarger area of cutting zone results in lesser TA. However, due the presence of large quantity of wood particles in the cutting zone made the slight diversion of material removal rate by larger grain size which results in a slight increase of TA as seen in Figure. Based on this analysis, the optimal combination of input parameters for lower SR is SoD (3 mm, level 3), WP (100 MPa, level 1), NS (100 mm/min, level 1) and AGS (80 mesh, level 2).



Mean of TA for different input levels

ANOVA Analysis

ANOVA analysis carried out in Minitab 17 software for investigating the effect of machining parameters of AWJM process on WDFRP composites and the result as shown in Tables. In this analysis, larger F-value indicates that the variation of the process parameter makes an extreme change on the performance. While P-value (i.e. probability value) is less than 0.05, shows the significance of the parameters.

The ANOVA result depicted in Table shows that, the parameter WP is the most significant parameter for SR. Because, the P value of WP is less than 0.05 and F value of WP is acceptable. This indicates that parameter WP is very essential in the case of SR 2.Moreover,as per the result depicted in (Table) shows that the parameter SoD and AGS are found to be more significant process parameters because of larger F value (i.e. 0.36 for AGS) and lesser P value (i.e. 0.0477 for AGS). However, interaction parameter i.e. SoD and AGS is found to be significant3 in case of TA as seen in Table .

Table. Analysis of variance for SR

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	1	0.001504	0.001504	2.59	0.052
WP	1	0.001504	0.001504	2.59	0.052
Error	7	0.004064	0.000581		
Total	8	0.005568			

Table . Analysis of variance for TA

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	3	0.045855	0.015285	0.59	0.0646
SoD	1	0.009173	0.009173	0.36	0.0477
AGS	1	0.007217	0.007217	0.28	0.0519
SoD × AGS	1	0.012980	0.012980	0.50	0.0312
Error	5	0.128828	0.025766		
Total	8	0.174683			

Mathematical model

A mathematical model is developed by using regression analysis to predict performance response of AWJM by using following Equations:

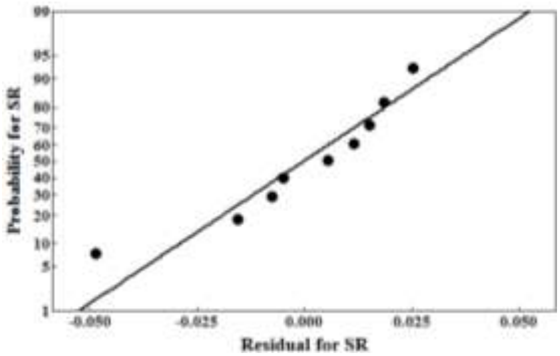
$$SR = 0.0714 + 0.000633 WP \quad ..... (2)$$

$$TA = -0.30 + 0.385 SoD - 0.0092 AGS - 0.00570 SoD \times AGS \quad (3)$$

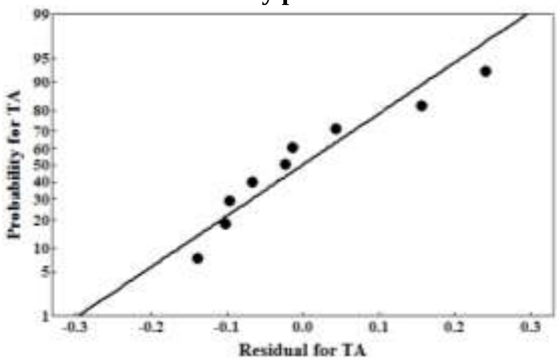
It is seen from the Eq. (2), the variables such as WP is positive effective. Because of this, WP is influencing parameters. While, from Eq. (3) SoD has a positive effect, and AGS has a negative effect as well as interaction SoD and AGS have a negative effect. This is because process variables SoD is most influencing process parameters in the case of TA. Also, forward elimination method is

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 2 Feb 2021, pp: 604-611 www.ijaem.net ISSN: 2395-5252

used to remove insignificant parameters to adjust the fitted quadratic model.



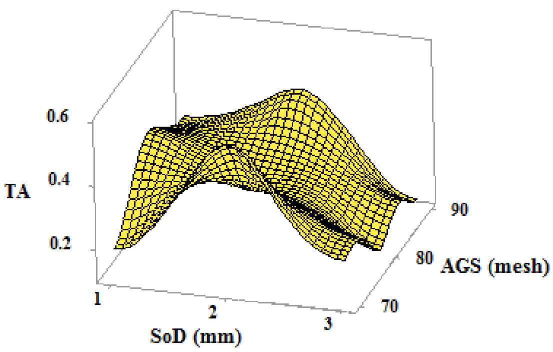
Probability plot for SR



Probability plot for TA

Moreover, the graphical representation shows in Figures that all points of the responses for SR, and TA are closer to the straight line. Hence, it is represented that the experimental data are normally distributed. The output responses of AWJM closely follows the fitting curve as shown in the figure. This shows congruence of the experimental and predicted data.

Additionally, the interaction study for TA is also carried out based on the ANOVA analysis. The interaction plot for TA is represented by plotting the response surface plots as shown in Figure.



Response surface plot of SoD and AGS for TA

It can be incurred from figure that the magnitude of TA is less for SoD as 3 mm and AGS as 80 mesh. This is attributed to the fact that large size abrasive particles having more kinetic energy at higher SoD produce a higher material removal rate due to water jet flow, resulting in lesser TA. But the very small size of grain size, i.e. (<80 mesh) or very large grain size, i.e.(>80 mesh) could not penetrate the material uniformly, resulting in lesser TA. For such reasons, an intermediate value of AGS is preferred for the experiment.

V. CONFIRMATION ANALYSIS

A further authentication of the optimum results acquired through parametric analysis is concluded by performing the confirmatory test. An optimality test is performed by comparing the result obtained by mathematical model and a confirmatory test. The result of confirmatory tests, including prediction, is depicted in Table 5. The result shows that predicted result for AWJM

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 2 Feb 2021, pp: 604-611 www.ijaem.net ISSN: 2395-5252

responses i.e. TA and SR obtained from the mathematical model is comparable with the confirmatory test results.

VI. CONCLUSION

The present paper performs the parametric analysis to investigate the effect of each parameter on SR and TA by using main effect plots and optimal setting for lesser SR and TA is established. The parametric setting SR and TA are SoD (3 mm, level 3), WP (125 MPa, level 2), NS (100 mm/min, level 1) and AGS (90 mesh, level 3). And SoD (3 mm, level 3), WP (100 MPa, level 1), NS (100 mm/min, level 1) and AGS (80 mesh, level 2).Further, ANOVA and regression analysis is carried out to determine most significant parameters. The results show that the parameter WP is the most significant in the case of SR while SoD and AGS with interaction are most significant in the case of TA. Afterward, a confirmatory test is performed to verify the obtained results from the parametric analysis with experimental and prediction results. The results show that the confirmatory test results and prediction results are comparable.

ACKNOWLEDGEMENT

The author would like to thanks, Jet work, Pune, India, for allowing to carry out experiments and to utilize his valuable resources at a Dardi Waterjet Cutting Systems, Pune. The author also thanks, Proof Rajat Gupta, I/C Director NIT Silchar for his constant inspiration towards the research and all support at NIT Silchar.

Table. Confirmatory test results

Response Parameters	Input Parameters				Exp. Results	Optimum Parameters				Predicted Result	Confirmatory Test Result
	SoD (mm)	WP (MPa)	NS (mm/min)	AGS (mesh)		SoD (mm)	WP (MPa)	NS (mm/min)	AGS (mesh)		
SR	1	125	200	80	0.143	3	125	100	90	0.130	0.131
TA	3	100	300	80	0.118	3	100	100	80	0.108	0.111

REFERENCES

[1]. Al Bakri, A. M. M., Liyana, J., Norazian, M. N., Kamarudin, H., and Ruzaidi, C. M., 2013, "Mechanical Properties of Polymer Composites with Sugarcane Bagasse Filler," Adv. Mater. Res., Vol.740(August), pp. 739–744.

[2]. Konig, W., Wulf, C., Gral, P., and Willerscheid, H., 1985, "Keynote- Papers Machining of Fibre Reinforced Plastics," Vol.34, pp. 537–548.

[3]. Kumar,Rahul,Kumar,Kaushik Bhowmik,Sumit, 2014, "Optimization of Mechanical Properties of Epoxy Based Wood Dust Reinforced Green Composite Using Taguchi Method," Int. Conf. Adv. Manuf. Mater. eEngineering, Vol.5, pp. 688–696.

[4]. Miguel, L., Durão, P., Gonçalves, D., Tavares, J. M. R. S., and Albuquerque, V. H. C. De, 2014, "Delamination in Carbon / Epoxy Plates Drilling : Tool and Feed Rate Effect António Manuel Rincon de Aguiar Vieira and António Paulo Monteiro Baptista," Vol.49(4).

[5]. Koronis, G., Silva, A., and Fontul, M., 2013, "Green Composites: A Review of Adequate Materials for Automotive Applications," Compos. Part B Eng., Vol.**44,** No. 1, pp. 120–127.

[6]. Azmir, M. A., Ahsan, A. K., and Rahmah, A., "Effect of Abrasive Water Jet Machining Parameters on Aramid Fibre Reinforced Plastics Composite," Int. J. Mater. Form., Vol.2, No.1, pp. 37–44, 2009.

[7]. Badgujar, P. P., and Rathi, M. G., "Taguchi Methos Implementation in Abrasive Waterjet Machining Process Optimization," Int. J. Eng. Adv. Technol., Vol.**3**, No. 5, pp. 66–70, 2014.

[8]. Ahmad, J.,Machining of Polymer Matrix Composites, 2014.

[9]. Albuquerque, V. H. C. De, Marques, J. F. S., Andrade, O. N. G., Engenharia, F. De, Doutor, R., Frias, R., Fortaleza, U. De, and Queiroz, E., "Drilling Damage in Composite Material," pp. 3802–3819,2014.

[10]. Shanmugam, D. K., Chen, F. L., Siores, E., and Brandt, M., "Comparative Study of Jetting Machining Technologies over Laser Machining Technology for Cutting

Composite Materials," Compos. Struct., Vol.**57,** No.(1–4), pp. 289–296, 2002.

[11]. Lemma, E., Chen, L., Siores, E., and Wang, J.,"Study of Cutting Fiber-Reinforced Composites by Using Abrasive Water-Jet with Cutting Head Oscillation," Compos. Struct., Vol.**57,** No.(1–4), pp. 297–303, 2002.

[12]. A.A.Shaikh1, P. S. J., "Experimental Study of Various Technologies for Cutting Polymer," Int. J. Adv. Eng. Technol.

[13]. Oksman, K., and Selin, J.-F., "Plastics and Composites from Polylactic Acid," Natural Fibers, Plastics and Composites, Springer US, Boston, MA, pp. 149–165, 2004.

[14]. Bhowmik, S., and Ray, A., "Prediction and Optimization of Process Parameters of Green Composites in AWJM Process Using Response Surface Methodology," Int. J. Adv. Manuf. Technol., pp. 1–12, 2016.

[15]. Mhamunkar, M., "Optimization of Process Parameter of CNC Abrasive Water Jet Machine For Titanium Ti 6Al 4V Material," Vol.**3,** No.3, pp. 1640–1646, 2016.

[16]. Sachidananda, H. K., and Lecturer, S., "An Investigation on Surface Roughness in," Vol.**2,** No.3, pp. 125–128, 2013.

[17]. Korat, M. M., and Acharya, G. D., "A Review on Current Research and Development in Abrasive Waterjet Machining," J. Eng. Res. Appl., Vol.**4,** No.1, pp. 423–432, 2014.

[18]. Kechagias, J., Petropoulos, G., and Vaxevanidis, N., "Application of Taguchi Design for Quality Characterization of Abrasive Water Jet Machining of TRIP Sheet Steels," Int. J. Adv. Manuf. Technol., Vol.**62,** No.(5–8), pp. 635–643, 2012.

[19]. Rajasekaran, T., Palanikumar, K., and Vinayagam, B. K., "Application of Fuzzy Logic for Modeling Surface Roughness in Turning CFRP Composites Using CBN Tool," Prod. Eng., Vol.**5,** No.2, pp. 191–199, 2011.

[20]. Rao, R. V., and Kalyankar, V. D., "Optimization of Modern Machining Processes Using Advanced Optimization Techniques: A Review," Int. J. Adv. Manuf. Technol., pp. 11

International Journal of Advances in Engineering and Management
ISSN: 2395-5252

IJAEM

Volume: 03 Issue: 02 DOI: 10.35629/5252

www.ijaem.net
Email id: ijaem.paper@gmail.com