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Manufacturing and Optimization of Process Parameters by using Abrasive Water Jet Machining of Carbon Fibre Reinforced Polymer Composites

Jayprakash Umap, Shantanu Shelke, Satyam Tripathi, Omkar Karande, Abhimanyu Chandgude

Abstract*: In the last decade, invention of new material is the point of interest of researchers. Carbon composite epoxy is one of those materials, which are currently used in transportation, aerospace, structural as well as naval applications. It is very difficult to machine those carbon composite materials using traditional methods, so an updated solution for this issue is machining using Abrasive Water Jet. Significant input parameters namely Standoff Distance, Abrasive Mass Flow Rate and Traverse Rate are varied for various outputs, out of which kerf width is main point of focus. For précised values, Kerf Width measurement is carried out using Profile Projector. The process parameters were further optimized using GRA and Taguchi method. Regression models were developed for correlation with actual generated data using experiments. The result obtained using Optimization technique and Taguchi method is confirmed using confirmation experiment. The parameters were optimized for Kerf Width of carbon fibre with reference to input parameters by using AWJM.

Keywords*: Abrasive Mass Flow Rate, Abrasive Water Jet Machining, Carbon Fibre Reinforced Polymer, Kerf Width, Standoff Distance, Traverse Speed.

I. INTRODUCTION

It is very difficult to machine CFRP due to having non homogeneity and anisotropy. For small kerf Width we should have high Water pressure, small SOD and Traverse rate. [1]. Kerf Width can be minimized by working at moderate Transverse Rate, high Water pressure, and large abrasives at high Mass flow rate. Better kerf geometry can occur at high Abrasive Flow Rate [2]. The kerf Width measurement also can be validated in stacks. The influence shows that the selected parameters are used to obtain the best results for high traverse speed and abrasive flow rate.[3] The AWJM is also used for drilling of CFRP. For kerf width only pressure is significant. Material removal increases with increase in pressure. [4]. The SOD and feed rate have significant influence on Kerf width. Pressure, SOD, Flow rate and Transverse speed has to be varied to plot different Graphs and to observe main influencing parameters on KW [5]. SOD and Traverse Rate are the most significant parameters which affect the kerf width. High Standoff distance produces large taper angle due to having exposure of the surface of material to the jet [6]. Many times, L18 orthogonal array (OA) is used to optimize machining parameters. A surface roughness tester having diamond stylus with diameter of 10 µm and tip angle 90º can be used as surface Roughness measuring instrument [7]. The study reveals that the kerf width increases by increase in TS and AMFR, while it is less affected by the SOD [8]. Water pressure and SOD are the significant parameters which affect the material removal rate and kerf characteristics of the CFRP samples [9]. Different phases are based on material constitutive law, failure initiation criterion and damage evolution criterion. The fibre orientations have a significant influence on the removal of CFRP [10]. Taguchi method with GRA and orthogonal L9 array is used to optimize the input parameters. Laser cutting is economical for machining of Ti6Al4V sheet up to 2 mm thick but beyond that AWJM has to be used [11]. the optimization of input parameters can determine by (ANOVA) and Taguchi method. The SR can be measured using Taylor Hobson Equipment [12]. The AWJM equipment uses Abrasive material as Garnet sand. Abrasive material has a density of 2300 kg/m^3. The Graphs of S/N ratio vs. MRR and SR are can be considered [13]. Input parameters are optimized based on (S/N) ratio. The regression model and optimization technique has improved input process parameters to achieve desired SR in AWJM process [14]. With Taguchi method ANOVA is can be taken in to account to find optimum parameters. Different Graphs are plotted to observe main influencing parameter SR [15].

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***** Correspondence Author
Jayprakash Umap, Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India. Email: umapjayprakash@gmail.com
Shantanu Shelke, Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India. Email: shantanu7743@gmail.com
Satyam Tripathi, Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India. Email: tripathisatyam932@gmail.com
Omkar Karande, Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India. Email: onkarande75@gmail.com
Abhimanyu Chandgude, Assistant Professor, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India. Email: akchandgude@mech.mitaoe.ac.in

II. METHODOLOGY

Stage 1: Manufacturing of CFRP Epoxy

For manufacturing of CFRP Bidirectional Carbon Fiber Epoxy polymer laminate (300*300*12) mm was used to perform experiment.

Fig.1 Shows manufacturing CFRP laminate which 60% carbon fibre & 40% epoxy.

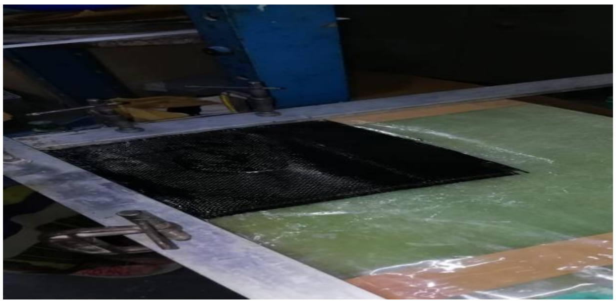

Fig. 1. Manufacturing of CFRP

Stage 2: Machining of CFRP

Machining of CFRP includes Siemens S3015 AWJM which was used for experimentation integrated with KMT Waterjet System with high pressure pumps. S3015 means 3m for movement in X axis & 1.5 m for movement in Y axis. The maximum hydraulic pressure of AWJM is 400 Mpa and it can cut up to thickness of 3000mm.

Fig. 2 AWJM Equipment Fig. 3Machined CFRP Epoxy

Stage 3: Measurement of Kerf Width

Measurement of Kerf width has been carried using the Profile Projector present at the laboratory of Metrology and Quality Control. Placement of CFRP manufactured material on the glass further illuminates from below and the produced image is then picked on the microscope. Profile Projector has been used due to having the more accuracy for Kerf Width results.

Fig.4 Measurement of KW Using Profile Projector

Table 1. Input Process Parameters

Parameters	Unit	1	2	3	4
SOD	mm	0.5	1.5	2.5	3.5
AMFR	g/min	200	400	600	800
TS	mm/min	30	70	110	150

A) KW Measurement

Table 2. KW Values

Sr.No.	SOD	AMFR	TS	KW
1	0.5	200	30	1.2975
2	0.5	400	70	1.4875
3	0.5	600	110	1.6075
4	0.5	800	150	1.71
5	1.5	200	30	2.1975
6	1.5	400	70	2.7075
7	1.5	600	110	1.1825
8	1.5	800	150	1.5925
9	2.5	200	30	2.5625
10	2.5	400	70	2.125
11	2.5	600	110	2.1525
12	2.5	800	150	1.3875
13	3.5	200	30	1.975
14	3.5	400	70	1.4825
15	3.5	600	110	2.7225
16	3.5	800	150	2.6525

B) Taguchi Method –Minitab Software

Taguchi technique has been carried out with the help of MINITAB Software which further uses L16 array to optimize process parameters. Significance of S/N ratio is used to evaluate deviation from precise value. S/N ratio is a logarithmic function in which signal proportionate to mean and noise proportionate to standard deviation. Kerf Width is optimized on the basis of smaller is better characteristics.

$$\left(\frac{S}{N}\right)_{STB} = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

Where n= no. of experiments
And y_i is the response value for i^{th} experiment.

C) Grey Relational Analysis:

Full optimization of the factors is done by considering the all responses GRA is applied. Following table 3. Show the Deviation sequence with grey relation Coefficient and values are ranked according to the values of Grey relation Grade (GRG).

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Table 3. Grey Relational Analysis

SR	KW	SR	KW	GRG	RANK
-0.137	-0.889	1.379	-1.286	0.031	10
-0.231	-0.725	1.859	-2.224	-0.122	12
-0.321	-0.632	2.796	-3.794	-0.332	14
-0.418	-0.558	6.118	-8.669	-0.850	15
-0.117	-0.257	1.306	2.057	1.121	6
-0.260	-0.007	2.087	1.013	1.034	7
-0.275	-1.000	2.225	-1.000	0.408	9
-0.442	-0.643	8.592	-3.495	1.699	3
-0.087	-0.073	1.211	1.170	0.794	8
-0.163	-0.297	1.486	2.465	1.317	5
-0.471	-0.282	17.243	2.290	6.511	1
-0.935	-0.808	-1.150	-1.622	-0.924	16
0.000	-0.385	1.000	4.344	1.781	2
-0.126	-0.729	1.336	-2.185	-0.283	13
-0.374	0.000	3.961	1.000	1.654	4
-1.000	-0.031	-1.000	1.067	0.022	11

D) Regression Model:

Normal Probability plot is drawn by using Regression model for Kerf Width in CFRP laminates by AWJM. The values R-Sq. is used to expresses that the input process parameter is well fitted approximately at a confidence level. The accuracy in fit can be achieved by eliminating insignificant source and by re-examine the experiments.

III. RESULT AND DISCUSSION

A) Taguchi Method:

Final Experiment has been carried out on CFRP Epoxy Laminates for various values of Input Process Parameters and thus by using Taguchi Graphs of S/N Ratio Vs. SOD, TS and AMFR has obtained for optimization of this parameters and then results has been analyzed on the basis of smaller is better value of S/N Ratio from the below plots**.**

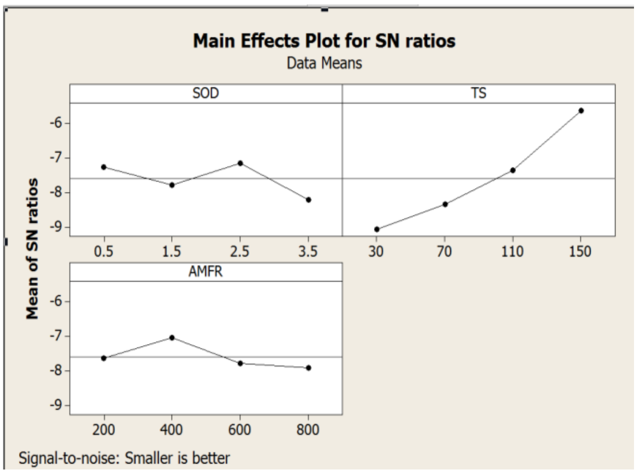

Fig. No. 5 Taguchi method Graph

B) Grey Relational Analysis:

Experiment 11. Shows the best performance characteristics from 16 experiments due to highest GRG and highest rank i.e. Rank = 1. So, the values for best multiple performance characteristics are obtained as given in results.

C) Regression Model:

Normal Probability plot is drawn by using Regression model for Kerf Width the value of R- Sq. is used to expresses that the input process parameter is well fitted approximately at a confidence level. It shows that optimality of Process parameters is achieved. Regression equation for Kerf with:

Avg. KW = 0.926 + 0.2184 SOD – 0.003752 TS + 0.001804 AMFR

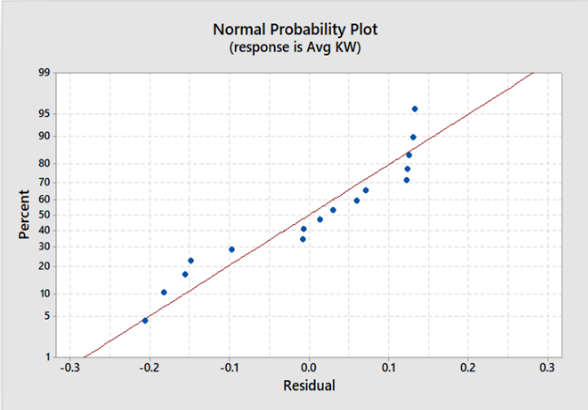

Fig.No.6 Normal Probability Plot

D) Graphs of Individual Input Parameters:

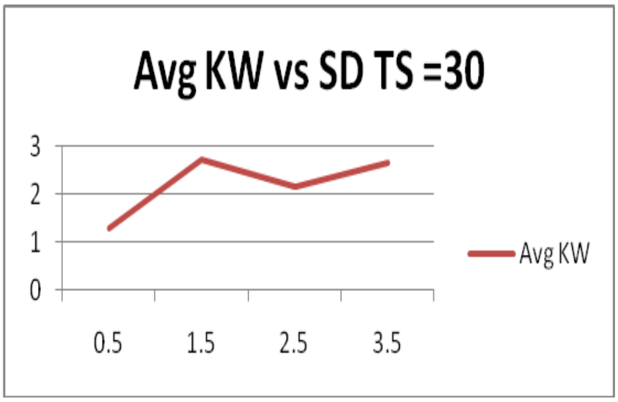

Fig. No.7 KW vs. SOD @ TS=30 mm/min

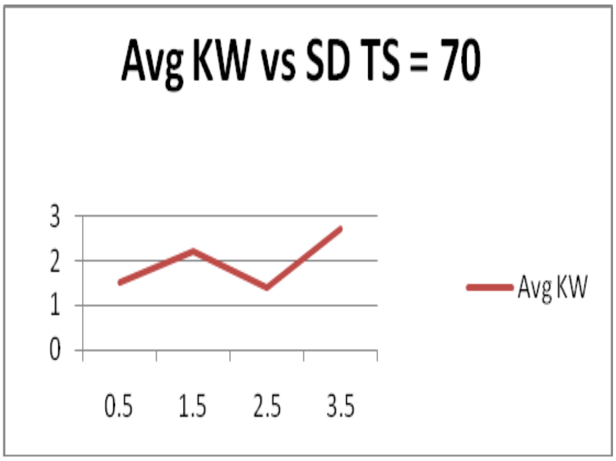

Fig. No. 8 KW vs. SOD @ TS=70 mm/min

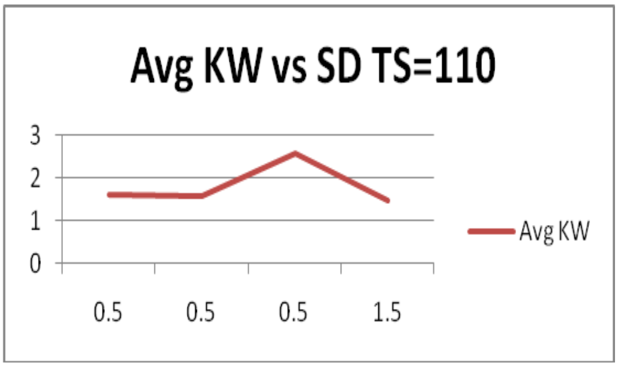

Fig. No. 9 KW vs. SOD @ TS=110 mm/min

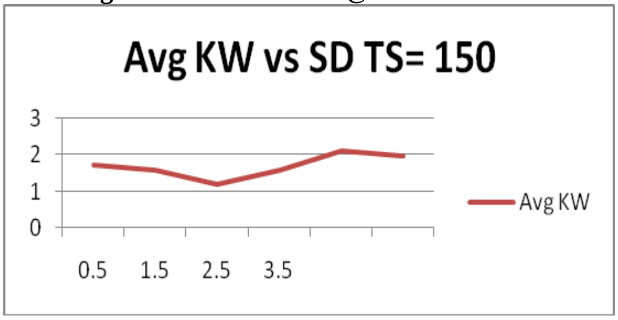

Fig. No. 10 KW vs. SOD @ TS=150 mm/min

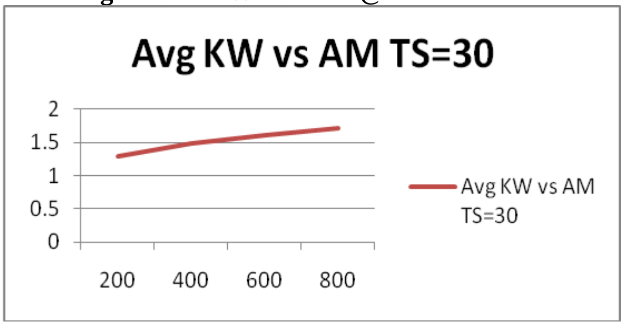

Fig. No. 11 KW vs. AM @ TS=30 mm/min

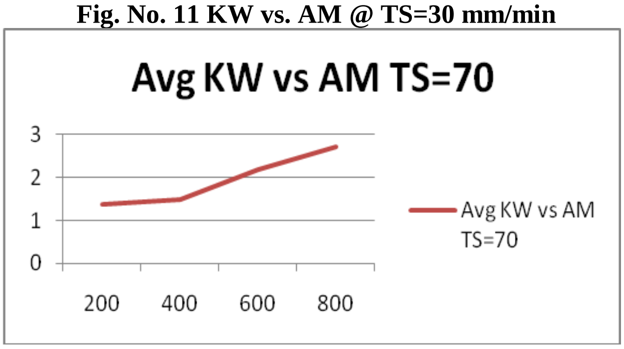

Fig. No.12 KW vs. AM @ TS=70 mm/min

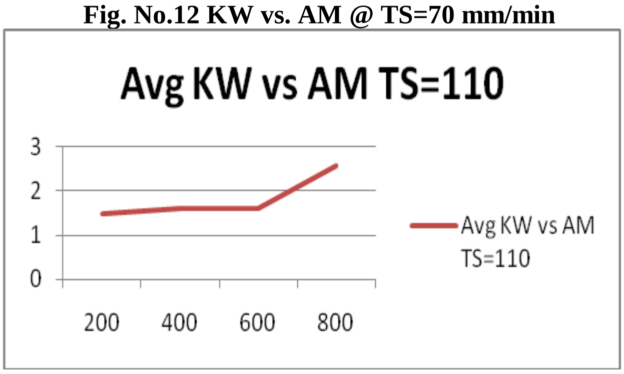

Fig. No.13 KW vs. AM @ TS=110 mm/min

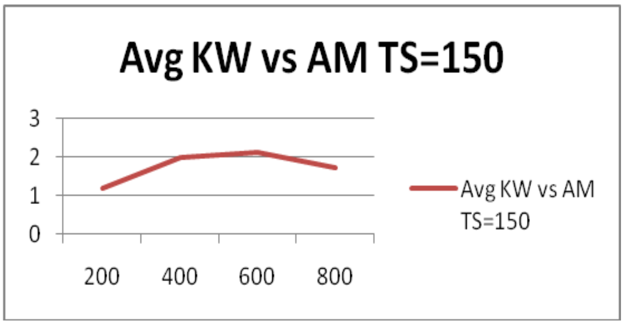

Fig. No. 14 KW vs. AM @ TS=150 mm/min

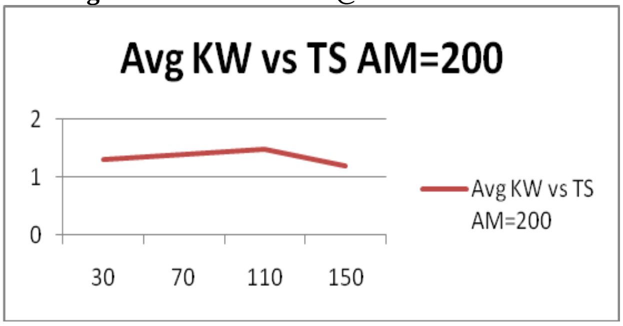

Fig. No. 15 KW vs. TS @ AM=30 gm/min

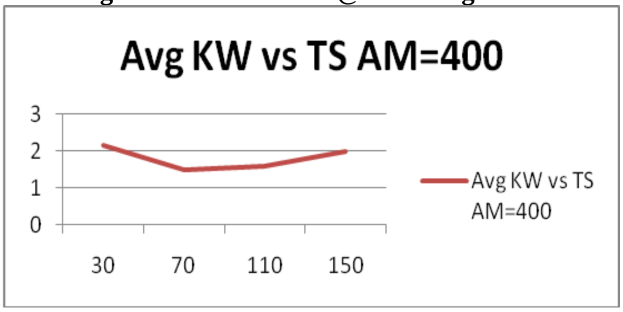

Fig. No.16 KW vs. TS @ AM=400 gm/min

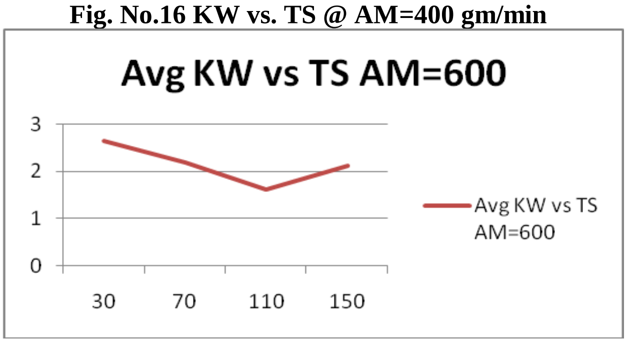

Fig. No. 17 KW vs. TS @ AM=600 gm/min

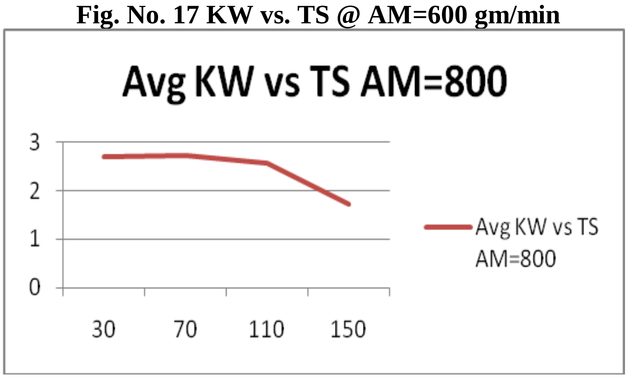

Fig. No. 18 KW vs. TS @ TS=800gm/min

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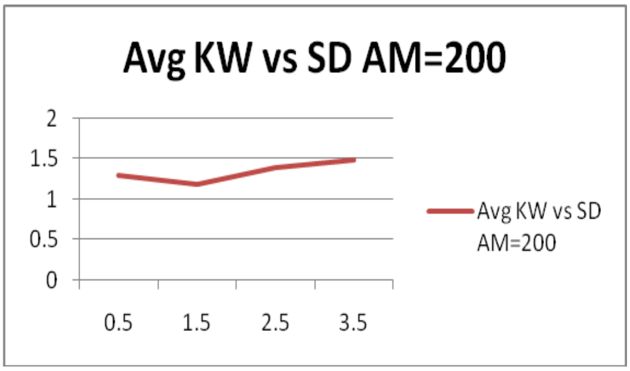

Fig. No.19 KW vs. SOD @ AM=200 gm/min

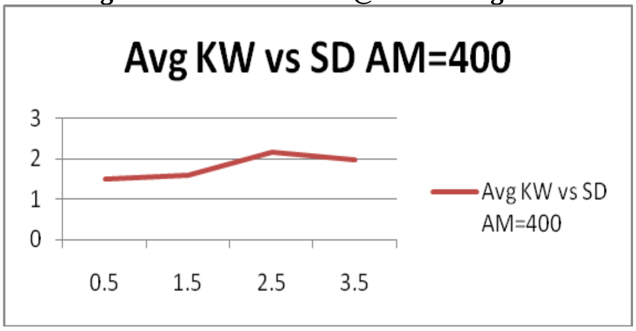

Fig. No.20 KW vs. SOD @ AM=400 gm/min

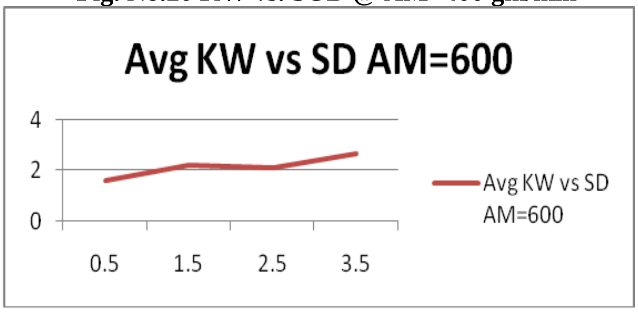

Fig. No.21 KW vs. SOD @ AM=600 gm/min

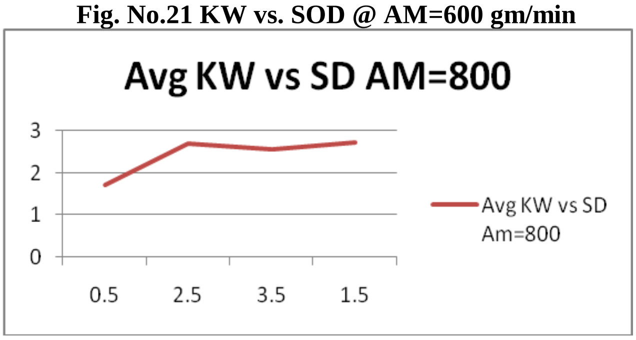

Fig. No. 22 KW vs. SOD @ TS=800 gm/min

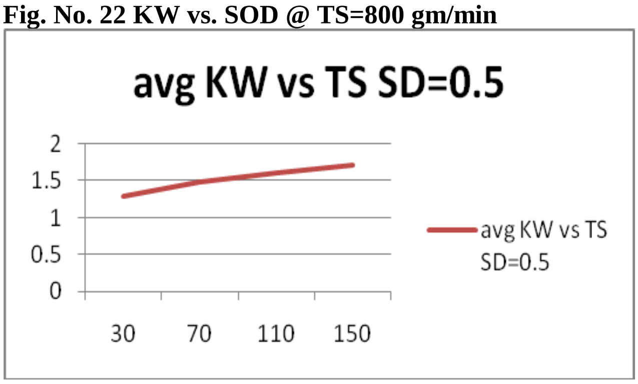

Fig. No.23 KW vs. TS @ SD=0.5 mm

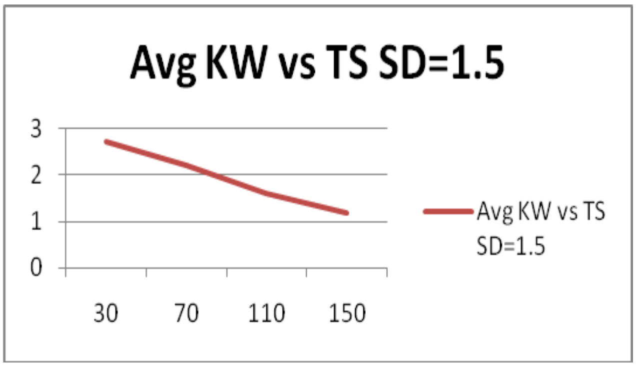

Fig. No.24 KW vs. TS @ SD=1.5 mm

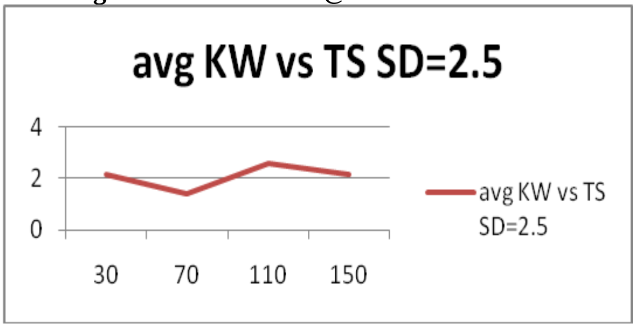

Fig. No.25 KW vs. TS @ SD=2.5 mm

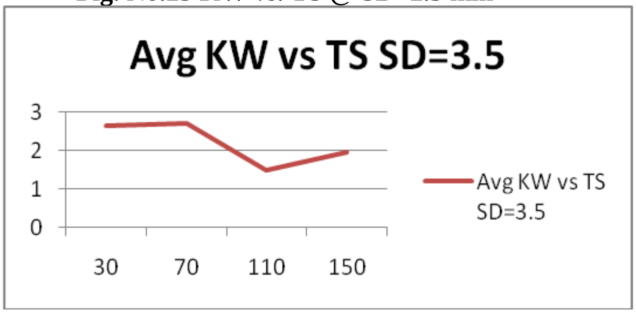

Fig. No.26 KW vs. TS @ SD=3.5 mm

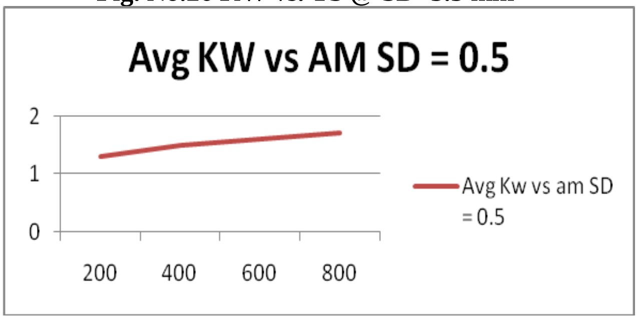

Fig. No.27 KW vs. AM@ SD=0.5 mm

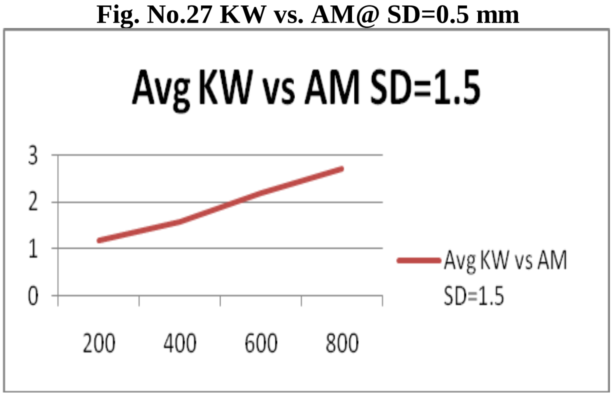

Fig. No.28 KW vs. AM @ SD=1.5 mm

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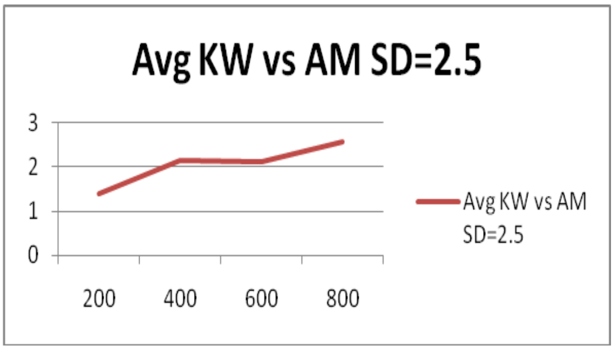

Fig. No.29 KW vs. AM @ SD=2.5 mm

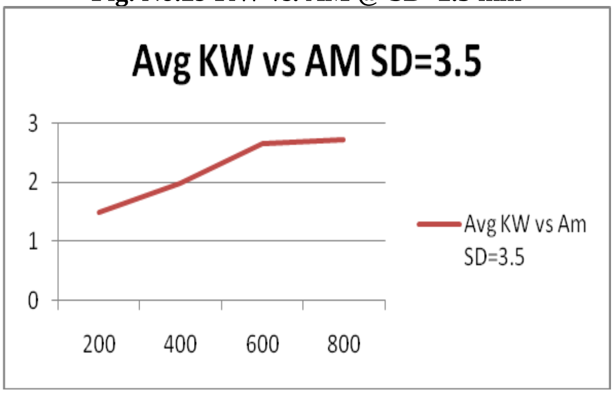

Fig. No.30 KW vs. AM @ SD=3.5 mm

E) Regression Analysis- Residual vs. Order

The results were further analyzed and determined. Residual plots for KW are shown in figure. The plot shows that 14th experiment of L16 orthogonal array at SOD 3.5 mm, TS 70 mm/min & AMFR 400gm/min does not fit within the normal distribution

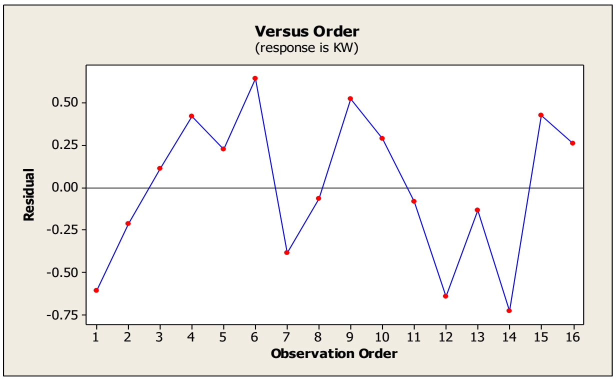

Fig. No. 31 Residual vs. Order.

F) Experimented Results:

Table. 4 Graph Results

Fig. No.	SOD (mm)	TS (mm/min)
7	0.5	30
8	2.5	70
9	1.5	110
10	2.5	150
	AM (gm/min)	**TS (mm/min)**
11	200	30
12	400	70
13	200	110
14	200	150
	TS (mm/min)	**AM (gm/min)**
15	150	200
16	70	400
17	110	600
18	150	800
	SOD (mm)	**AM (gm/min)**
19	1.5	200
20	0.5	400
21	0.5	600
22	0.5	800
	TS (mm/min)	**SOD (mm)**
23	30	0.5
24	150	1.5
25	70	2.5
26	110	3.5
	AM (gm/min)	**SOD (mm)**
27	200	0.5
28	200	1.5
29	200	2.5
30	200	3.5

Table 5. Optimized results

Sr.No.	Techniques	Results Obtained
1	Taguchi Method	SOD = 3.5 mm AMFR = 800 gm/min TS = 30 mm/min
2	Grey Relational Analysis	SOD = 2.5 mm AMFR = 600 gm/min TS = 110 mm/min
3	Regression Model	R-Sq.=94.74%(accuracy)

IV. CONCLUSION

In this project Performance of KW has been observed by varying the Input parameters like Abrasive Mass Flow Rate, SOD and Traverse Speed on material Carbon fibre Epoxy composite (bi-directional) using standard AWJM. Optimality of Kerf Width is obtained using following techniques:

1. Taguchi Technique – one of the basic techniques used for optimization and comparing the results of different experiments using MINITAB software which gave optimized results.
2. Grey Relational Analysis – It has given précised and accurate results compared to Taguchi Technique. Here best Rank is predicted using GRG values.
3. Regression Model – includes Deviation regression equation, Normal probability plot and residual vs. order of experiment plot which gives fitness and accuracy of optimality.

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AUTHORS PROFILE

Mr.Jayprakash Umap Btech Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India.

Mr.Shantanu Shelke Btech Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India.

Mr.Satyam Tripathi Btech Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India.

Mr.Omkar Karande Btech Student, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India.

Mr. Abhimanyu Chandgude Assistant Professor, School of Mechanical and Civil Engineering, MIT Academy of Engineering, Alandi, Pune, Maharashtra, India.