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# Performance Analysis of Process Parameters on Machining of Aluminium Composite Panel using AWJM process

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***Abstract: The recent trends shows that numerous new materials are rapidly emerging and developed. It creates considerable interest in the researcher to search out the optimum combination of machining parameters during machining of these materials using advanced machining processes. Abrasive water jet cutting is a non-traditional machining method that offers a productive alternative to conventional techniques. It uses a fine jet of ultra-high pressure water and abrasive slurry to cut the target material by means of erosion. In order to obtain a product with high surface quality, the abrasive water jet machining process must be precisely controlled. In this work, an experimental investigation is carried out on abrasive water jet machining (AWJM) process for the machining of aluminium composite panel using the Taguchi methodology. Parameters such as transverse speed, standoff distance and mass flow rate are considered to obtain the influence of these parameters on kerf taper angle surface roughness and deamination factor. ANOVA and Regression analysis are performed to identify the impact of process parameters on performance parameters.***
***Keywords: AWJM, Taguchi, ANOVA, Regression, Optimization***

## I. INTRODUCTION

Aluminium composite panels are flat panels consisting of two thin coil coated aluminium sheets bonded to a non-aluminium core. It is commonly used material by signage industry for providing artwork piece with better strength and aesthetics. The machining of ACP can be done with traditional as well as non-traditional ways of machining. In the case of traditional machining of ACP, in order to minimize the amount of heat generated and avoid thermal damage to the part, the proper tool geometry and operating conditions must be adopted. Precautions also should be taken to avoid introducing delamination in the work piece by limiting tool wear in order to keep machining forces low and by using back-up material to prevent delamination as the tool exist the work piece. So, Particularly in case of ACP composite if traditional machining is need to be done than, a specially designed tool will be required as well as there is also a need of backup material at the tool exit to avoid the amount of delamination. It will be difficult and costlier for industries.

The non-traditional machining of ACP is possible with various machining processes like EDM, LBM, ECM, ECDM and AWJM. The main problem associated with EDM process like deposition of resolidified layer that hampers the surface quality. Tool wear and tool breaking are another major problems combined with this process. The LBM produced surfaces are affected by the transformed microstructure of matrix material due to excessive heat, presence of striation pattern and dross attachment at the bottom. The formation of pits at low voltage due to low current density and formation of streak at low electrolyte flow rate due to low turbulence on the machined surface during ECM is obvious. In AWJM the material removal takes place by means of erosion not by deformation wear. The quality of machined surface highly depended on the size differences between abrasive and reinforcement particles in this case. So the AWJM process is preferable as the size difference in abrasive particles can be directly utilized for the improvement in surface roughness.

Industries commonly using AWJM processes to deal with counter shape cutting of ACP panels. Due to the globalization, the competition between the industries in the market is increasing. In such period of time, it is important for any industry to provide the quality product in relatively smaller period of time with lower cost. The optimization of available process parameters for desired performance parameter can be helpful for industries to meet such requirements. The performance parameters like delamination, MRR, kerf geometry, surface roughness can be improved with the optimization of process control parameters like water pressure, abrasive flow rate, transverse speed, standoff distance, material thickness, nozzle diameter etc.Abrasive Water Jet machining (AWJM) was first developed in 1974 to clean metal prior to surface treatment of the metal. AWJM process belongs to mechanical group of nonconventional machining processes. Generally, AWJM cuts 10 times faster than the conventional machining methods of composite materials. It is an extended version of water jet cutting process, which is developed to increase the material removal rate of the process. In this process mechanical energy of water jet and abrasive particles are used for the material removal or machining of the work. Almost any type of material ranging from hard brittle material like metal, glass and ceramic to extremely soft material such as foam or rubber can be easily and accurately machined by this process. This process is ideal for the materials that cannot be cut by laser, electron beam or thermal cut. In case of AWJ machining, the amount of heat generation on the machined surface is negligible. So the thermal properties of the work remain unchanged.

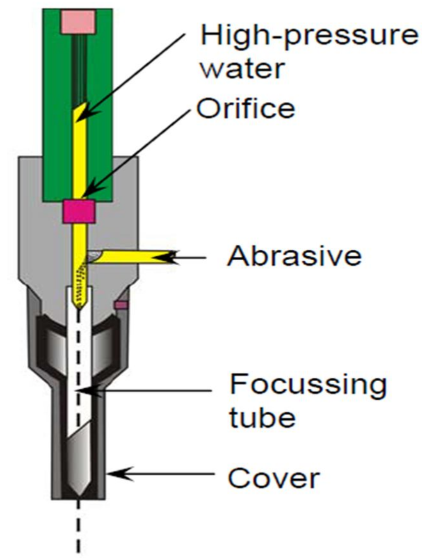



Fig. 1 AWJM Nozzle

Many investigations have been conducted to understand the effects of the process variables on the cutting performance measures, such as material removal rate, kerf geometry, delamination and surface roughness. Kerf geometry is a characteristic of major interest in abrasive water jet cutting. AWJ will generally open a tapered slot with the top kerf being wider than the bottom kerf, kerf taper or kerf taper angle normally θ being used to represent this characteristic.

## II. LITERATURE REVIEW

A number of researchers have investigated parametric influence of AWJM on a wide variety of materials. Rajkamal et al. [1] conducted experiments of AWJM processing on AA6351- T6 (AlMgSi1) aluminium wrought alloy as a specimen material. The influence of transverse speed on kerf top width and taper angle was found. Standoff distance and mass flow rate doesn't shows much impact on kerf top width or taper angle. Vishal et al. [2] carried out an experiment on makrana marble by considering process parameters as were nozzle traverse speed, water pressure and abrasive mass flow rate. Performance parameter considered as a quality product were kerf taper angle and top width. They found relation of nozzle transverse speed and water pressure for top kerf width. Only nozzle transverse speed was significantly affecting the kerf taper angle.

Preeti et al. [3] find a relation between water pressure and abrasive flow rate with material removal rate. They reported that standoff distance doesn't show any influence on material removal rate. K S Jai et al. [4] studied five different process parameters for improving material removal rate and surface roughness of Al 6061. The result shows that water pressure, abrasive flow rate and standoff distance are influencing for improving the MRR or to provide good surface finish. Orifice diameter and focusing nozzle diameter were minor influencing parameters for both performance parameters. Vasant S et al. [5] used water pressure, abrasive flow rate, feed rate and standoff distance as process parameters and surface roughness as a performance parameter while experimenting on Titanium (Ti-6Al-4V) alloy. Authors concluded that abrasive flow rate and standoff distance has the most significant role on determining surface quality. Dhruv N Dani et al. [6] performed an experiment on granite. They have used three process parameters i.e. Traverse Speed, Water Pressure and Stand-off Distance. The focused performance parameters were material removal rate and surface roughness. The results shows that traverse speed is the most affecting factor for MRR, followed by water pressure and stand-off distance. Stand-off distance was found as the most significantly affecting factor for Surface Roughness, followed by Traverse speed and Water Pressure.

S. Thirumalai Kumaran et al. [7] performed experiment on CFRP composites. They found relation of jet pressure, transverse speed and standoff distance on the quality of surface roughness. B Jagdeesh et al. [8] found relation of standoff distance and transverse speed on surface roughness and kerf taper angle on the investigation on GFRP. Pratik Bose et al. [9] get impact of water pressure and abrasive flow rate on surface roughness for GFRP composites. Ajit Dhanawade et al. [10] used stand-off distance, jet pressure, traverse speed, and abrasive mass flow rate as a performance parameters and delamination and kerf geometry as performance parameter while experimenting on carbon epoxy composites. The result shows that delamination mainly depends on water pressure, abrasive flow rate and transverse speed whereas kerf taper ratio depends on transverse rate and SOD. Irina Wong MM et al. [11] found relation of standoff distance and transverse rate for the value of kerf ratio.

Thus, literature review reviles that kerf geometry is mainly depends on transverse speed of jet and slightly on water pressure. For composites it depends on standoff distance also. Major parameters influences on MRR are water pressure and abrasive flow rate. Surface roughness is mainly depends process parameters according to the material. Variation on its dependence is also seen. Abrasive flow rate, transverse speed and standoff distance are important process parameter to get better kerf geometry and surface roughness. The dependency of performance parameters on process parameters may vary according to change in material. So, Final conclusion can't be made without doing an experiment on that particular material.

## III.EXPERIMENTAL WORK

### *A. Material*

The material used in present study is aluminium composite panel. The samples of ACP were prepared with size of 120mm × 120 mm from the sheet of ACP with thickness of 4 mm.

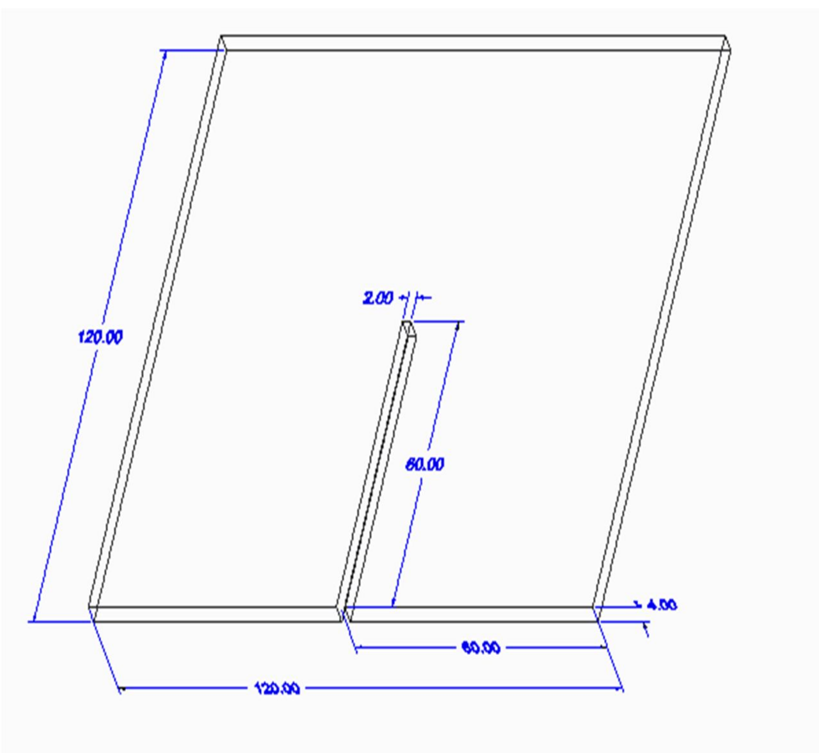



Fig. 2 Specimen CAD Model

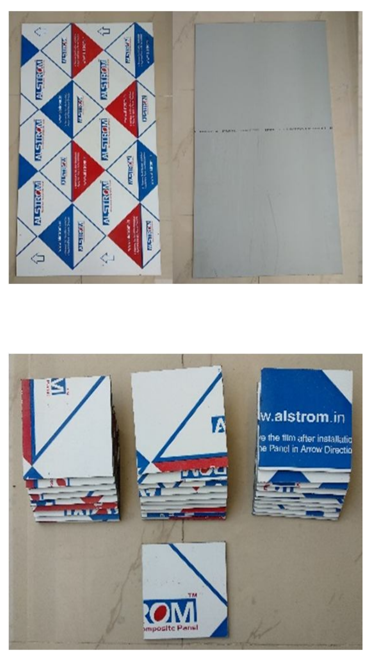


Fig. 3 ACP Samples

### *B. Equipment*

The equipment used for machining the samples was OMAX 55100 abrasive water jet machine equipped with a vibratory feed type of abrasive hopper, an abrasive feeder system, a pneumatically controlled valve and a work piece table.

TABLE 1
MACHINE SPECIFICATIONS [12]

| Item | Description |
|---|---|
| AWJM system | Pressure Intensifier, injection type nozzle |
| Power | 3-Phase, 380-480 VAC ±10%,<br>50-60 Hz |
| Maximum Discharge Pressure | 5200 psi |
| Abrasive feeding system | Automatic type vibratory conveyor |
| CNC Work Table | 3200 × 1651 mm2 |
| Abrasive Material | Garnet |
| Abrasive particle shape | Angular (random) |
| Mesh number | 80 |
| Work piece material | Aluminium Composite Panel |
| Nozzle diameter (mm) | 0.25 |
| Jet impact angle (°) | 90º |

### *C. Experimental Design*

TABLE 2
VARIABLE PROCESS PARAMETERS

| Parameter | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Abrasive flow rate (AFR) | gm/min | 50 | 100 | 150 |
| Transverse Speed (TS) | mm/min | 50 | 75 | 100 |
| Stand-off Distance (SOD) | mm | 0.8 | 0.9 | 1 |

In the present study, three machining parameters were selected as control factors as shown in Table 2. The parameters and levels were selected on the bases of literature review on AWJM. Based on Taguchi's method design of experiment with three factors a L27 orthogonal arrays table with 27 rows was selected for the experimentation.

The surface roughness was measured with surface roughness tester from the manufacture Mitutoyo with model SJ210.The kerf top and bottom width was measured with vision inspection system. Kerf taper angle is calculated with the following equation.

$$\theta = \frac{W_t - W_b}{2t}$$

Where, $W_t$ is value of top width of kerf. $W_b$ is value of bottom width of kerf and t is thickness of work piece. Delamination factor is calculated with an equation $d_f = W_{max}/W$. Where, $W_{max}$ is maximum width of cut and W is width of cut.

## IV. RESULT AND DISCUSSION

TABLE 3
OBSERVED DATA FROM THE EXPERIMENT

| Run | AFR | TS | SOD | KTW | KBW | KTA | SR | DF |
|---|---|---|---|---|---|---|---|---|
| 1 | 50 | 50 | 0.8 | 2.2145 | 2.0245 | 1.3605 | 1.452 | 1.10725 |
| 2 | 50 | 50 | 0.9 | 2.3645 | 2.1845 | 1.2889 | 2.754 | 1.18225 |
| 3 | 50 | 50 | 1 | 2.3875 | 2.2708 | 0.8358 | 3.413 | 1.19375 |
| 4 | 50 | 75 | 0.8 | 2.2425 | 2.0234 | 1.5688 | 1.125 | 1.12125 |
| 5 | 50 | 75 | 0.9 | 2.3249 | 2.1214 | 1.4572 | 2.681 | 1.16245 |
| 6 | 50 | 75 | 1 | 2.4145 | 2.2421 | 1.2345 | 3.524 | 1.20725 |
| 7 | 50 | 100 | 0.8 | 2.2458 | 1.9808 | 1.8972 | 1.532 | 1.1229 |
| 8 | 50 | 100 | 0.9 | 2.2875 | 2.0625 | 1.6111 | 2.884 | 1.14375 |
| 9 | 50 | 100 | 1 | 2.4652 | 2.2969 | 1.2052 | 3.168 | 1.2326 |
| 10 | 100 | 50 | 0.8 | 2.3684 | 2.2002 | 1.2045 | 3.653 | 1.1842 |
| 11 | 100 | 50 | 0.9 | 2.4268 | 2.2607 | 1.1895 | 4.781 | 1.2134 |
| 12 | 100 | 50 | 1 | 2.4654 | 2.3664 | 0.7089 | 5.492 | 1.2327 |
| 13 | 100 | 75 | 0.8 | 2.3645 | 2.1738 | 1.3655 | 2.624 | 1.18225 |
| 14 | 100 | 75 | 0.9 | 2.4232 | 2.2462 | 1.2675 | 4.267 | 1.2116 |
| 15 | 100 | 75 | 1 | 2.4965 | 2.3856 | 0.7942 | 5.456 | 1.24825 |
| 16 | 100 | 100 | 0.8 | 2.3262 | 2.1065 | 1.5731 | 3.654 | 1.1631 |
| 17 | 100 | 100 | 0.9 | 2.4237 | 2.2425 | 1.2975 | 5.445 | 1.21185 |
| 18 | 100 | 100 | 1 | 2.4515 | 2.3138 | 0.9861 | 4.984 | 1.22575 |
| 19 | 150 | 50 | 0.8 | 2.3579 | 2.1985 | 1.1415 | 2.244 | 1.17895 |
| 20 | 150 | 50 | 0.9 | 2.4566 | 2.2992 | 1.1271 | 3.557 | 1.2283 |
| 21 | 150 | 50 | 1 | 2.4887 | 2.3991 | 0.6417 | 4.946 | 1.24435 |
| 22 | 150 | 75 | 0.8 | 2.3246 | 2.1212 | 1.4564 | 2.454 | 1.1623 |
| 23 | 150 | 75 | 0.9 | 2.4617 | 2.2878 | 1.2453 | 4.369 | 1.23085 |
| 24 | 150 | 75 | 1 | 2.5224 | 2.3682 | 1.1042 | 3.823 | 1.2612 |
| 25 | 150 | 100 | 0.8 | 2.3486 | 2.1245 | 1.6046 | 2.644 | 1.1743 |
| 26 | 150 | 100 | 0.9 | 2.4526 | 2.2697 | 1.3097 | 4.224 | 1.2263 |
| 27 | 150 | 100 | 1 | 2.5118 | 2.3707 | 1.0105 | 5.586 | 1.2559 |

The results of the AWJM experiment on aluminium composite panel are shown in table 3. Performance of quality of cut is checked with performance parameters kerf taper angle (KTA), surface roughness (SR) and delamination factor (DF).

### *A. Data analysis using response graph method*

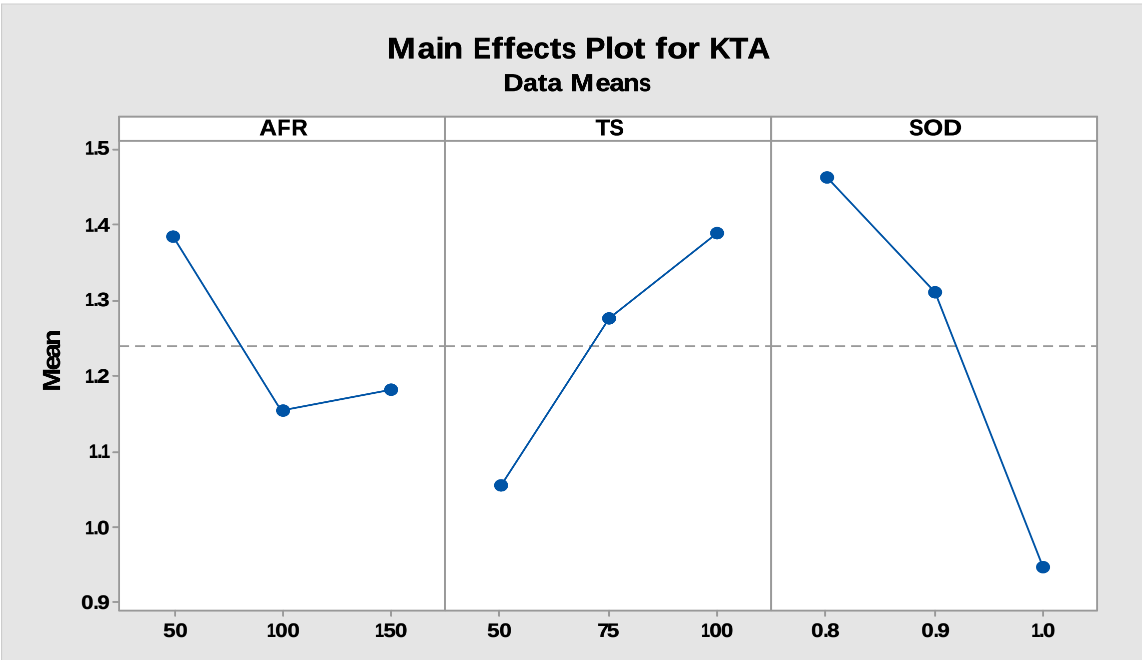
Firstly, the average response tables are prepared according to the levels of process parameters. The mean for each level is calculated for every process parameters. Than delta value for each process parameter is identified by subtracting the smaller value from the larger one. The rank to the process parameters is given according to the delta values. Rank is a measure of dependency of performance parameters on process parameter i.e. 1$^{st}$ rank of process parameter shows that performance parameter is strongly dependent on it. 2$^{nd}$ rank means less dependency and so on. The response graph are plotted according to the response table and optimum condition for the machining is identified. The data analysis using response graph method is done for all the three performance parameters i.e. Kerf taper angle (KTA), surface roughness (SR) and delamination factor (DF). It is explained in the following sections.

1) *Kerf taper angle (KTA):* The response table and graph are given in table 4 and fig. 3 respectively. For KTA, SOD is the highest influencing parameter. TS and AFR put less impact on KTA. As AFR increases, KTA decreases up to certain level and then start increasing. KTA increases with increase in TS. As SOD increase the KTA is decreases. The optimum condition for machining is AFR2-TS-1-SOD3.

TABLE 4
RESPONSE TABLE FOR KTA

| Level | AFR | TS | SOD |
|---|---|---|---|
| 1 | 1.3844 | 1.0554 | 1.4636 |
| 2 | 1.1541 | 1.2771 | 1.3104 |
| 3 | 1.1813 | 1.3883 | 0.9468 |
| Delta | 0.2303 | 0.3330 | 0.5168 |
| Rank | 3 | 2 | 1 |

Fig. 3 Response graph of KTA




2) *Surface Roughness (SR):* The response table and graph are given in table 5 and fig. 4 respectively. For SR, SOD is the highest influencing parameter. TS and AFR put less impact on SR. As AFR increases, SR increases up to certain level and then start decreasing. SR decreases up to certain level with increase in TS and then start increasing. As SOD increase the KTA is increases. The optimum condition for machining is AFR1-TS2-SOD1.

TABLE 5
RESPONSE TABLE FOR SR

| Level | AFR | TS | SOD |
|---|---|---|---|
| 1 | 2.504 | 3.588 | 2.736 |
| 2 | 4.484 | 3.369 | 3.885 |
| 3 | 3.761 | 3.791 | 4.488 |
| Delta | 1.980 | 0.422 | 2.112 |
| Rank | 2 | 3 | 1 |

3) *Delamination Factor (DF):* The response table and graph are given in table 6 and fig. 5 respectively. For DF, SOD is the highest influencing parameter. TS and AFR put less impact on SR. As AFR increases, DF also increases. DF increases up to certain level with increase in TS and then start decreasing. As SOD increase the DF is also increases. The optimum condition for machining can be achieved from the response graph shown in fig. 5. To get the best result for each process parameter, the level should be set at AFR1-TS3-SOD1.

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TABLE 6
RESPONSE TABLE FOR DF

| Level | AFR | TS | SOD |
|---|---|---|---|
| 1 | 1.164 | 1.196 | 1.155 |
| 2 | 1.208 | 1.199 | 1.201 |
| 3 | 1.218 | 1.195 | 1.234 |
| Delta | 0.054 | 0.003 | 0.078 |
| Rank | 2 | 3 | 1 |

Fig. 4 Response graph of SR

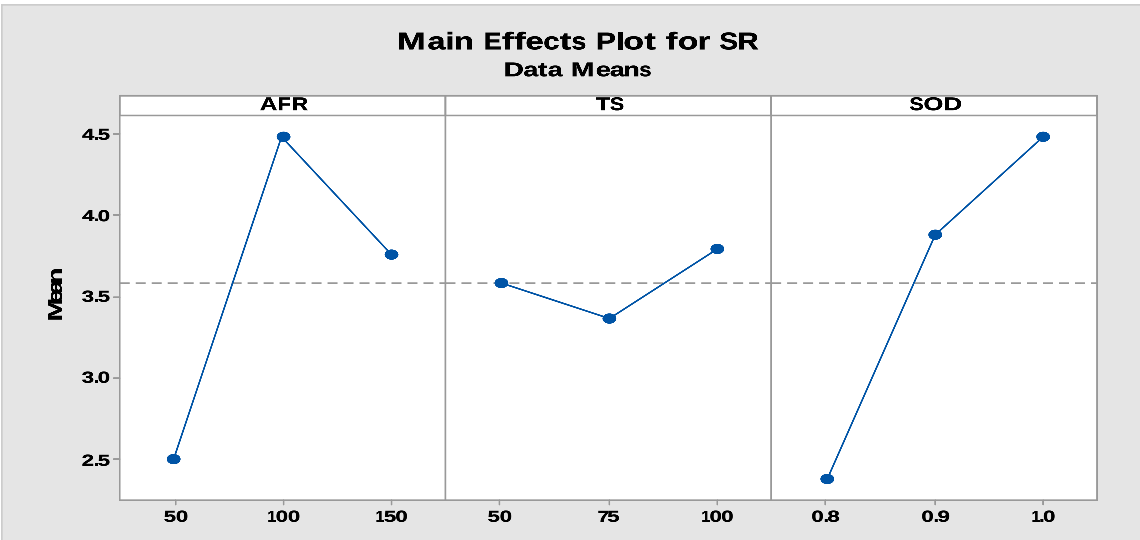
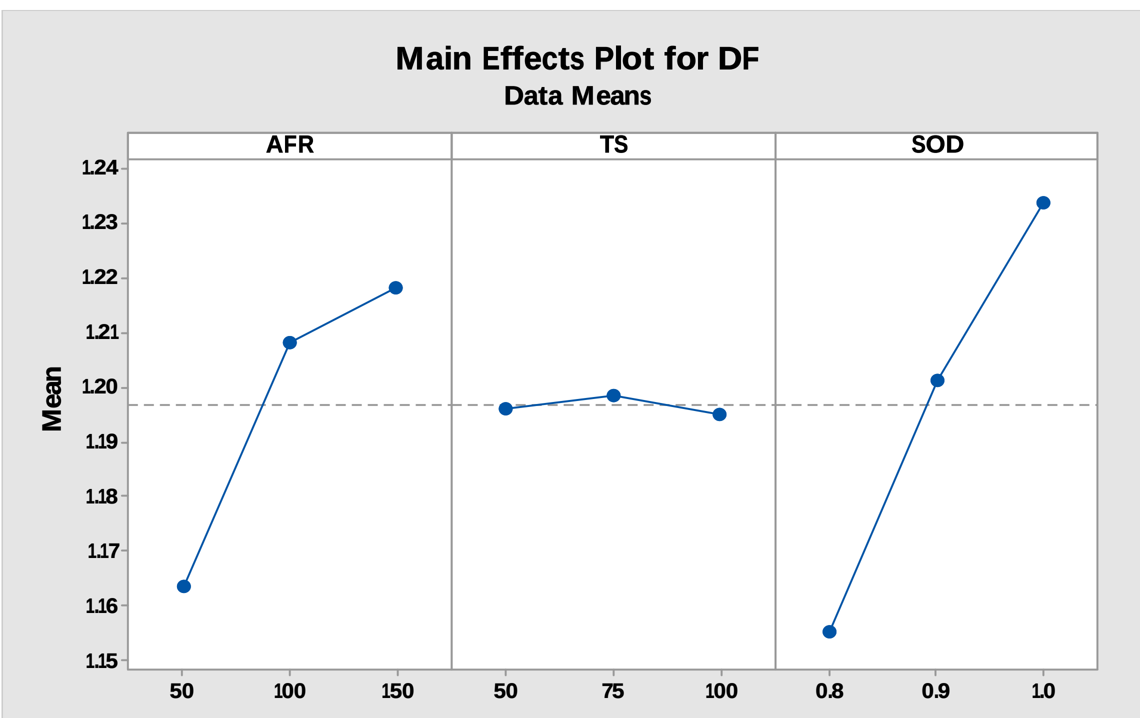



Fig. 5 Response graph of DF



### B. Data analysis using ANOVA

ANOVA is a method of partitioning total variation into accountable sources of variation in an experiment. It is a statistical method used to interpret experimented data and make decisions about the parameters under study. ANOVA for all the three performance parameters is calculated and contributing factors are identified.

1) *Kerf taper angle (KTA):* ANOVA table for KTA is shown in table 7. The maximum impact on KTA is of SOD i.e. 57%. The contribution of TS is 23.2% followed by AFR i.e. 12.7%. The contribution of error is 6.8%, which shows that model is acceptable.

TABLE 7
ANOVA FOR KTA

| Factor | Sum of Square | DOF | Mean Square | F-Value | P-Value | Contribution (%) |
|---|---|---|---|---|---|---|
| AFR | 0.283900394 | 2 | 0.141950197 | 18.53388 | 0.000 | 12.7741419 |
| TS | 0.51715691 | 2 | 0.258578455 | 33.76157 | 0.000 | 23.2695547 |
| SOD | 1.268225081 | 2 | 0.63411254 | 82.79357 | 0.000 | 57.0639826 |
| Error | 0.153179181 | 20 | 0.007658959 | | | 6.892320801 |
| Total | 2.222461565 | 26 | | | | |

2) *Surface Roughness (SR):* ANOVA table for SR is shown in table 8. The maximum impact on SR is of SOD i.e. 49.2%. The contribution of AFR is 41.7% followed by TS i.e. 1.8%. The contribution of error is 7.2%, which shows that model is significant. Impact of TS on SR is negligible.

TABLE 8
ANOVA FOR SR

| Factor | Sum of Square | DOF | Mean Square | F-Value | P-Value | Contribution (%) |
|---|---|---|---|---|---|---|
| AFR | 18.07529652 | 2 | 9.037648259 | 57.91931 | 0.000 | 41.73996883 |
| TS | 0.801740963 | 2 | 0.400870481 | 2.569047 | 0.102 | 1.851402148 |
| SOD | 21.30671852 | 2 | 10.65335926 | 68.27387 | 0.000 | 49.20205684 |
| Error | 3.120772074 | 20 | 0.156038604 | | | 7.206572183 |
| Total | 43.30452807 | 26 | | | | |

3) *Delamination Factor (DF):* ANOVA table for DF is shown in table 9. The maximum impact on DF is of SOD i.e. 59.7%. The contribution of AFR is 32.2% followed by TS i.e. 0.1%. The contribution of error is 7.9%, which shows that model is significant. Impact of TS on SR is negligible.

TABLE 9
ANOVA FOR DF

| Factor | Sum of Square | DOF | Mean Square | F-Value | P-Value | Contribution (%) |
|---|---|---|---|---|---|---|
| AFR | 0.01507 | 2.00000 | 0.00753 | 40.77403 | 0.00 | 32.24185 |
| TS | 0.00006 | 2.00000 | 0.00003 | 0.15321 | 0.859 | 0.12115 |
| SOD | 0.02791 | 2.00000 | 0.01396 | 75.53582 | 0.000 | 59.72955 |
| Error | 0.00370 | 20.00000 | 0.00018 | | | 7.90745 |
| Total | 0.04673 | 26 | | | | |

### C. Regression Analysis

It is used to relate the output (responses) with the input variables (factors) for making a prediction of the output with respect to input or for optimizing the process. The regression equations for Kerf taper angle (KTA), surface roughness (SR) and delamination factor (DF) are developed from the experimental results. The obtained equations are as follows,

1) *Kerf taper angle (KTA):* KTA = 3.268 - 0.002020 AFR + 0.00666 TS - 2.584 SOD
   The above equation can be used for prediction of taper angle while AWJM of ACP is done.
2) *Surface Roughness (SR):* SR = -7.48 + 0.01257 AFR + 0.00406 TS + 10.56 SOD
   The above equation can be used to predict surface roughness in AWJM of ACP.
3) *Delamination Factor (DF):* DF = 0.7911 + 0.000543 AFR - 0.000019 TS + 0.3918 SOD
   The above equation can be used to predict delamination factor in AWJM of ACP.

## V. CONCLUSION

In the present study, standoff distance is the most significant parameter for abrasive water jet machining of aluminium composite panel. It put 57%, 49.2% and 59.7% influence on KTA, SR and DF respectively. Abrasive flow rate is the second most influencing parameter in AWJM of ACP. 41.1% and 32.2% influence of abrasive flow rate is seen on SR and DF respectively. KTA is 12.7 % dependent on abrasive flow rate. Transverse speed gives an impact only on KTA i.e. 23.2%. SR and DF are not much influenced by transverse speed.

The minimum kerf taper angle can be achieved with minimum transverse speed, moderate abrasive flow rate and maximum standoff distance. Better surface finish and lower delamination can be achieved by lowering the abrasive flow rate and standoff distance.

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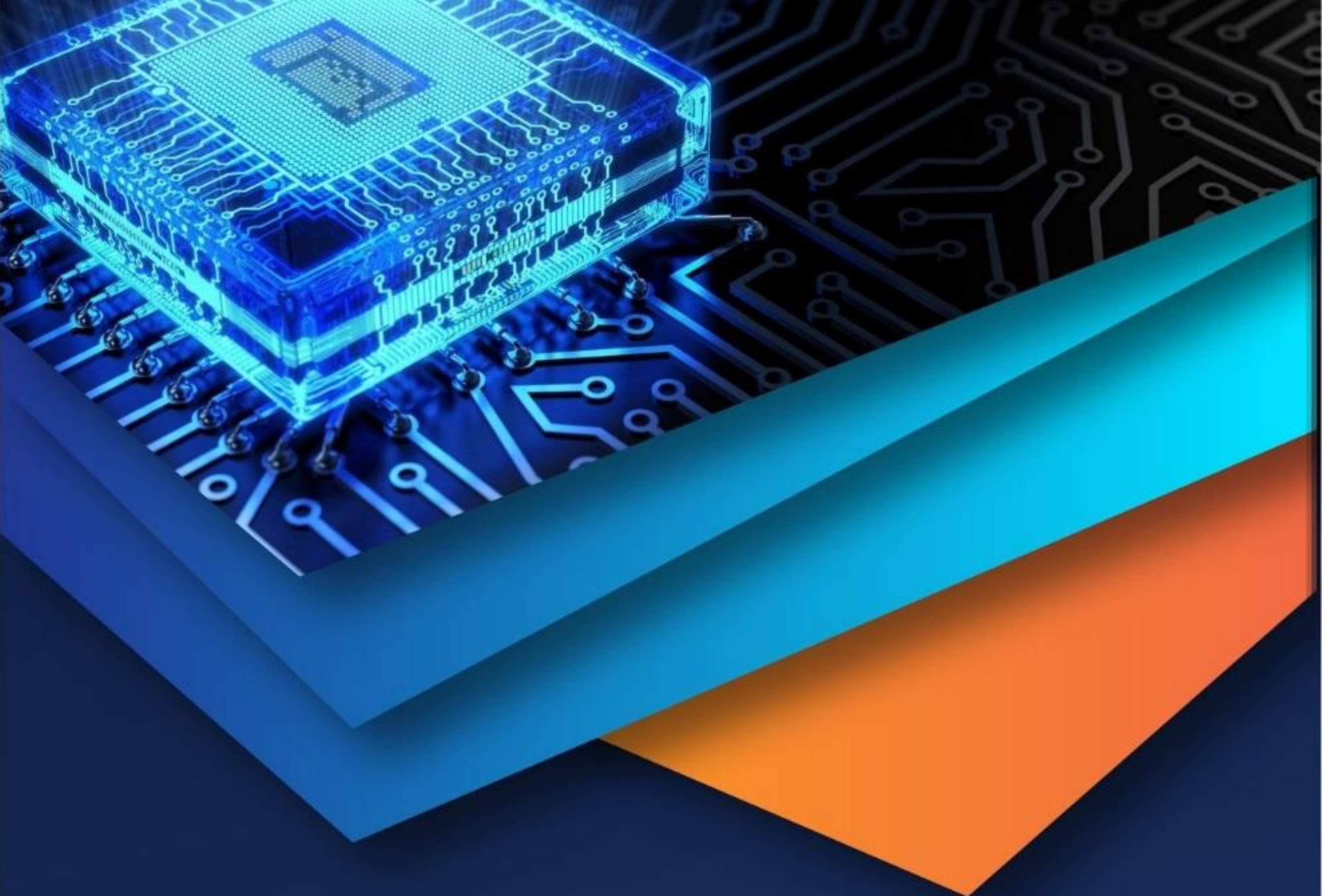

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