Non–Metallic Material Science
https://ojs.bilpublishing.com/index.php/nmms

REVIEW

Optimization of Input Parameters of AWJM: Using Three Different Abrasives on MS2062

Kusnurkar S.V[1] J.S.Sidhu[2*]

1. Assistant Professor, Dr D.Y Patil S.O.E.T Pune, Maharashtra, India
2. Associate Professor, Dept of Mech. Engineering, MGM's C.O.E, Nanded, Maharashtra, India

ARTICLE INFO

Article history
Received: 25 April 2019
Accepted: 26 April 2019
Published Online: 30 April 2019

Keywords:
Garnet
White aluminum oxide
Brown fused alumina
Nozzle transverse speed
Abrasive flow Rate
Standoff distance
Kerf angle
MRR
Taguchi
ANOVA

ABSTRACT

The objective of this work is to optimize input parameters of AWJM (Abrasive Water Jet Machining) such as Nozzle Transverse Speed (NTS), Abrasive Flow Rate (AFR) and Stand-off Distance (SOD) using three different abrasives Garnet, Brown Fused Alumina and White Aluminum Oxide on MS2062 and to compare their performance with surface finish, MRR and kerf angle. Experiments were conducted according to Taguchi's design of experiments. Analysis of variance is conducted to investigate the influence of each parameter on responses Three controllable parameters of three levels are applied for determining the optimal responses The results revealed that NTS is a most significant factor for MRR among three abrasives followed by AFR and SOD, with regards to surface finish and MRR White Aluminum Oxide has emerged as a most strong abrasive followed by Brown Fused Alumina and Garnet. It is recommended, to achieve the better surface finish, less kerf angle and good MRR White Aluminum Oxide be used in place of Garnet which is mostly used by the industry today.

1. Introduction

In water jet machining water is forced at a sufficiently high pressure through a small orifice in a nozzle (generally of 0.2- 0.4 mm diameter), causing high acceleration of water. The potential energy of water gets converted into kinetic energy which yields a very high jet velocity. The high pressure of the accelerating

Water particles develop fine cracks on the material surface, these fine cracks propagate further under the impact of high velocity water. The extended version of WJM is AWJM. In AWJM process, the particles of abrasives are added in the water jet in-order to enhance its cutting ability for harder materials. The AWJM are mainly of two types entrained and suspended type. In the entrained type the particles are allowed to draw in the water jet thereby forming an enhanced water jet with higher velocities.

In suspended type AWJM, mixture of abrasive and water takes place before the nozzle. In present work entrained type AWJM is used in which material is removed byerosion action of abrasive particles at a high velocity. A high velocity is obtained by passing particles through

**Corresponding Author:*
J.S.Sidhu;
E-mail: siddhu_js@mgmcen.ac.in.

  DOI: https://doi.org/10.30564/omms.v1i1.892

nozzle with compressed gas usually air. Different types of abrasives are used in abrasive water jet machining like Garnet (90%), Aluminum oxide, Silica sand, Silicon carbide. WJM is typically used to cut easy to machine materials like thin sheets and foils, wood, textiles, frozen meat but harder and difficult to cut materials like steel, aluminum, ceramics, granite, marble are only cut by AWJM. Many researchers have investigated parametric influence of AWJM on a wide variety of materials, few are discussed here, Vishal Gupta et.al.[1] used Garnet on Marble they selected input parameters water pressure, transverse speed and abrasive flow rate and output parameters were top kerf width, kerf geometry, they observed that transverse speed is most influencing factor for top kerf width. Karakurt et.al.[2] used Garnet on Granite taking input parameters abrasive flow rate, stand-off distance, water pressure, abrasive size and transverse speed and output parameters were cut depth and kerf geometry, they concluded that increase in transverse speed results in decrease in both cut depth and kerf width. Jborkowski et.al.[3] used synthetic abrading Silicon carbide as a abrasive material instead of Garnet on Mild steel, Brass and Aluminum alloys, they concluded that process of cutting with suspension water jet is most favorable if this abrasive is used. P.P. Badgujar et.al.[4] used Garnet on cold rolled steel SS304 considering input parameters water pressure, stand-off distance, abrasive grain size and output parameters as surface roughness they concluded that abrasive flow rate is most significant factor on surface roughness. P. Siddhe Reddy et.al.[5] used Garnet on Inconel 800 and concluded that machined surface is smoother near jet entrance and gradually rougher towards jet exit they have considered transverse speed, abrasive flow rate ,stand-off distance as a input parameters . LeeladharNagdaveetal.[6] used Garnet on Aluminum and concluded that pressure is most significant factor on MRR. KamleshThakkar et.al.[7] used Garnet on Mild Steel taking abrasive flow rate, stand-off distance and nozzle transverse speed as input parameters presents a study on influence of these parameters on MRR and surface roughness, observed abrasive flow rate is most significant for roughness, for MRR transverse speed plays major role but on other hand increase in transverse speed above certain limit cuts rougher surface. After going through literature survey it is observed that lot of work has reported on Marble, Granite, Acrylic mostly brittle materials but very little work is reported on Mild steel, it is also observed that only Garnet is used as abrasive material, so by taking this work further present work uses abrasives like Garnet, Brown fused alumina and White aluminum oxide on Mild Steel and seeking results with regards to surface finish, kerf angle and MRR.

2. Materials and Methods

2.1 Work Piece

Three work piece/specimens of MS 2062 were taken each (150mm×75×mm×20mm) as shown in Figure 1 and Figure 2. Chemical analysis and physical properties of MS 2062 are tabulated in Table 1 and Table 2 respectively.

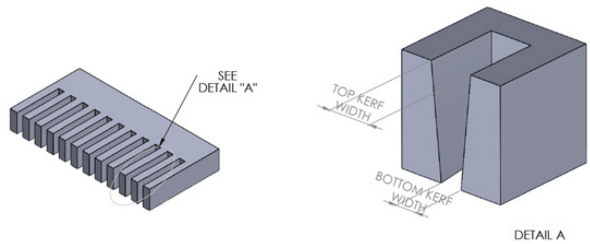

Figure 1. 3D view of work piece

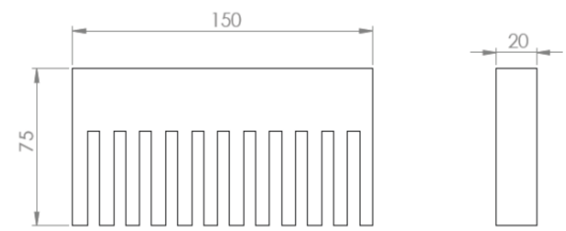

Figure 2. Two views of work piece

Table 1. Chemical analysis of MS 2062

Elements	Abbreviation	Percentage
Carbon	C	0.167
Manganese	Mn	0.71
Silicon	Si	0.198
Nickel	Ni	0.058
Chromium	Cr	0.010
Molybdenum	Mo	0.008
Sulphur	S	0.022
Phosphorus	P	0.017
Carbon equivalent	CE	0.293

Table 2. Physical properties of MS 2062

Property	Value
Tensile strength	410 MPA
Yield strength	240 MPA
Density	7850 kg/m^3
Hardness	72 HRB(approximately 4 Moh)

DOI: https://doi.org/10.30564/omms.v1i1.892

2.2 Abrasives

2.2.1 Abrasive I Garnet

This is chemically inert, natural mineral abrasive, popular as an expendable blast media offering a cleaner application than traditional expendables, with improved cutting performance, compatibility to non-ferrous metals and low tendency to embedment and good durability. Its hardness on Mohs scale is 8.

Applications:

a) Sand blasting: In the process of surface preparation, Garnet is blasted on to the surface of the steel with the use of high pressure compressed air. This process creates a profile

b) Water jet cutting: It is one of the latest and fast growing cutting technologies employed, widely used in cutting of Marble, Granite, Artificial Stones, Concrete, Aluminum, Titanium, high strength Steel and, Automotive Glass, Textiles, corrugated box board, Plastic laminates, Aerospace Composites,

c) Other Applications:

For stone washing of Denim fabrics, used in industrial flooring for its anti-skid properties, micronized form of Garnet is used for polishing glass face plates of Televisions, Computer Monitors and Optical Glasses. Polishing and Precision finishing of high pressure Valves and for Artistic engraving.

Figure 3. Garnet

2.2.2 Abrasive II Brown Fused Alumina

Brown fused alumina fused with bauxite of high Al_2O_3 content and additives in Arc electric furnace, it features high hardness, high indentation, good self-sharpening, good thermal stability and chemical durability, high temperature-resistance, corrosion-resistance, and is widely used in abrasive, refractory, ceramic, chemical engineering and metallurgical industries. Its hardness on Mohr's scale is 9.

Applications: Lapping and polishing processes, sandblasting, producing mold of precision casting etc.

Figure 4. Brown fused alumina

2.2.3 Abrasive III White Aluminum Oxide

White fused alumina (white fused alumina) is a synthetic corundum made of reduced fusion of high purity alumina powder and other fillings in electric arc furnace under 2000 degree above, White fused alumina, abbreviated as WA. Its main chemical content is aluminum oxide (Al_2O_3 99%min), and little sodium oxide (Na_2O), ferrous oxide (Fe_2O_3) and Silicon Oxide (SiO_2) because of its high content of Aluminum oxide, it is very hard, tough and sharp edged, and has very high refractory temperature. Its hardness on Mohr's scale is 9.5.

Applications: Grinding and cut off wheels, refractory and ceramic shapes, coated abrasives, laminates, coatings, investment casting shells, blasting abrasives ,lapping and polishing ,abrasive tools production, refractory materials, sand blasting, water-jet cutting, steel making, metallurgical, casting, foundry, ceramic industries

Figure 5. White aluminum oxide

2.3 Experimentation

Figure 6. KMT abrasive water jet machine and profile projector used in the present study

  DOI: https://doi.org/10.30564/omms.v1i1.892

The AWJM used in the present work is KMT JETLINE-50 SERIES water jet machine, with following Specifications.

Table 3. Specification of KMT JETLINE -50 AWJM

Table size	2006× 914×1183
weight	1202 kg
Power capacity	37 kw
Maximum water pressure	3792 Bar
Maximum flow rate	3.8 l/min
Orifice diameter	0.36 mm
Nozzle length	101 mm
Nozzle diameter	1.1 mm

KMT JETLINE-50 consist of following system a) Low pressure water system b) Recirculation system c) Hydraulic system d) High pressure water system e) Electrical system f) Operating system. The low pressure water system supplies the cutting water flow to the intensifier, the recirculation system is a cooling and filtration system that provides properly conditioned oil to the main hydraulic system, the hydraulic system supplies the intensifier with the hydraulic oil required to produce high pressure water .The high pressure water system is the heart of water jet system. Water is pressurized and continuously delivered to the cutting head, as water passes through a tiny hole in the orifice water pressure is converted into water velocity capable of cutting almost any material.

2.4 Design of Experiments

Taguchi uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Three parameters are considered as controlling factors. They are NTS, AFR and SOD, each parameter has three levels according to the Taguchi method, for three parameters and 3 levels L9 orthogonal array should be selected for experimentation. Table 4 shows design scheme of experiments.

Table 4. Design scheme of experiments

Input parameters	Level			Output parameters
	L1	L2	L3	
NTS mm/min	40	50	60	Kerf Angle
AFR kg/min	250	300	350	MRR
SOD mm	2	3	4	Surface finish

Table 5. Constant parameters

Fixed parameter	Set value
Water pressure	3800 bar
Orifice diameter	0.36 mm
Nozzle length	101 mm
Nozzle Diameter	1.1 mm
Work piece thickness	20 mm
Work piece material	MS 2062
Abrasives	Garnet ,Brown fused alumina Aluminum oxide
Abrasive size	80 mesh
Impact jet angle	90 degree

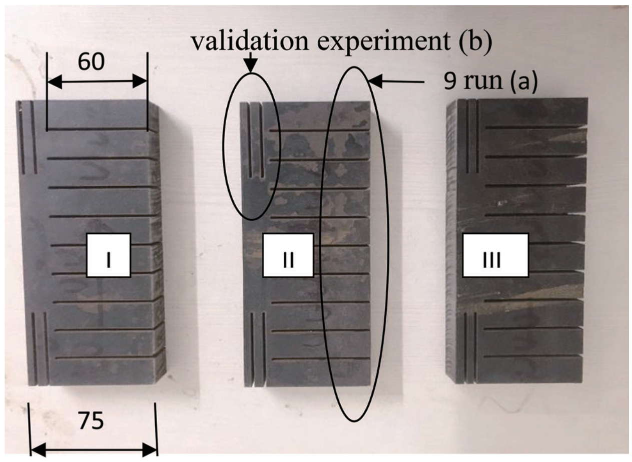

Figure 7. Specimens of MS 2062 using abrasive I, II and III (a)Experimental run (b) validation Experiment

2.5 Calculations

During experiment 9 runs were taken on each work piece with different abrasives all the specimens were cut with penetration of 20 mm and 60 mm in transverse direction as shown in Figure 7.Transverse Speed, Abrasive Flow Rate and Stand-off distance is controlled by controller .In order to quantitatively evaluate experimental results a measurement of kerf characteristics like top kerf width, bottom kerf width measured by means of profile projector , kerf taper angle, MRR are calculated and surface finish measured and observed.

Kerf angle is calculated from following relation

Kerf Angle =tan θ = $(W_t – W_b)/2T$

Where W_t is top kerf width in mm, $W_b$is bottom kerf width in mm; T is work piece thickness in mm or depth of penetration

MRR is calculated from following relation

MRR = $T×W_{avg}×N$

$W_{avg}= (W_t+ W_b) /2$ approximately equal to nozzle diameter is depth of penetration in mm, $W_{avg}$is average of

DOI: https://doi.org/10.30564/omms.v1i1.892

top and bottom kerf width in mm; N is nozzle transverse speed mm/min.

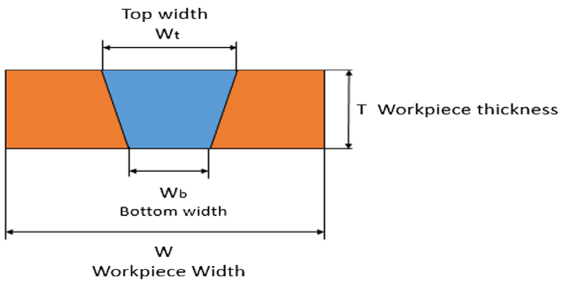

Figure 8. Kerf angle

Surface finish is decided on the basis of Ra value measured at 6 random locations on each work piece with Mitutoyo make surface tester (refer Figure 9) and tabulated in Table 6

Table 6. Comparative Ra value of three abrasives

abr	Ra_1	Ra_2	Ra_3	Ra_4	Ra_5	Ra_6	Ra
	1	2	3	4	5	6	Avg
1	8.62	3.69	1.66	3.90	2.53	2.78	3.86
2	5.21	6.43	2.53	2.64	3.69	2.39	3.81
3	2.28	4.62	4.57	2.14	3.13	2.13	3.15

Figure 9. Surface Tester used in present study

3. Results and Discussions

3.1 Results

Table 7. Results obtained with Garnet

NTS mm/min	AFR kg/min	SOD mm	Kerf angle degree	MRR mm^3/min
40	250	2	1.316	819.6
40	300	3	1.137	847.2
40	350	4	0.981	856.4
50	250	3	1.326	999
50	300	4	1.330	976.5
50	350	2	1.147	1017.5
60	250	4	1.187	1277.4
60	300	2	1.502	1104.6
60	350	3	1.390	1165.8

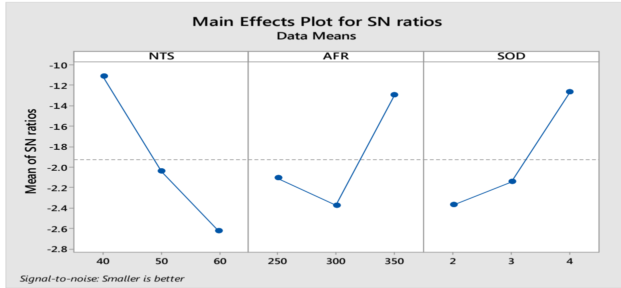

Figure 9. Main effect Plot for SN ratio Kerf angle vs factors using Garnet

From S/N ratio graph in case of Kerf angle Optimum values are NTS 40 mm/min, AFR 350kg/min, SOD 4 mm.

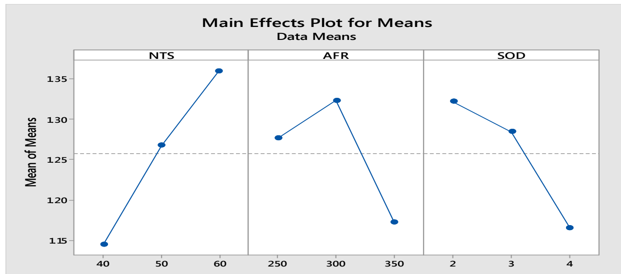

Figure 10. Main effect Plot for Means Kerf angle vs factors using Garnet

From data of Plot for means kerf angle increase as NTS increases. Kerf angle increases up to middle value and then falls in case of AFR and kerf angle reduces with increase in SOD.

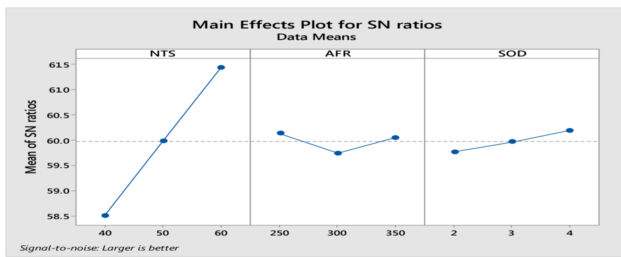

Figure 11. Main effect plot for SN ratio MRR vs factors using Garnet

In case of MRR Optimum values from S/N ratio are NTS 60 mm/min, AFR 250 kg/min, SOD 4mm.

Figure 12. Main effect Plot for Means MRR vs factors using Garnet

DOI: https://doi.org/10.30564/omms.v1i1.892

From data of plot for means MRR increases linearly with NTS MRR not shown any considerable effect with AFR and SOD.

Table 8. Abrasive 1 kerf angle ANOVA

Source	Rank	Contribution	F Value	P Value
NTS mm/min	1	35.11%	13	0.436
AFR kg/min	3	11.86%	0.66	0.603
SOD mm	2	19.93%	0.74	0.576

From ANOVA test NTS (contribution 35.11 % highest F value 1.3) is most significant factor followed by SOD (19.93%) ,AFR (17.86%).

Table 9. Response for SN ratio Abrasive 1 Kerf Angle

Level	NTS mm/min	AFR kg/min	SOD mm
1	-1.111	-2.108	-2.37
2	-2.04	-2.375	-2.142
3	-2.628	-1.295	-1.266
Delta	1.516	1.08	1.103
rank	1	3	2

Table 10. Abrasive 1 MRR ANOVA

Source	Rank	Contribution	F Value	P Value
NTS mm/min	1	91.20%	24.05	0.04
AFR kg/min	2	2.53%	0.67	0.6
SOD mm	3	2.49%	0.66	0.604

From ANOVA test NTS (contribution 91.20% highest F value 24.05) is dominating factor followed by SOD (0.67%) AFR (0.66%)

Table 11. Response for SN ratio abrasive 1 MRR

Level	NTS mm/min	AFR kg/min	SOD mm
1	58.5	60.13	59.76
2	59.98	59.74	59.96
3	61.44	60.05	60.19
Delta	2.95	0.39	0.43
Rank	1	3	2

Table 12. Validation experiment using Garnet

Optimum Parameters		Predicted optimum value using optimum setting	Actual value produced and Error
NTS	40 mm/min	Kerf angle 1.11 degree	Kerf angle 0.981degree Error = 13.14%
AFR	350 kg/min		
SOD	4 mm		
NTS	60 mm/min	MRR 1282 mm3/min	MRR 1277.4mm3/min Error = 0.360%
AFR	250 kg/min		
SOD	4 mm		

The validation experiment were conducted using the optimum combination of machining parameters obtained and results were compared and error was found as tabulated in Table 12

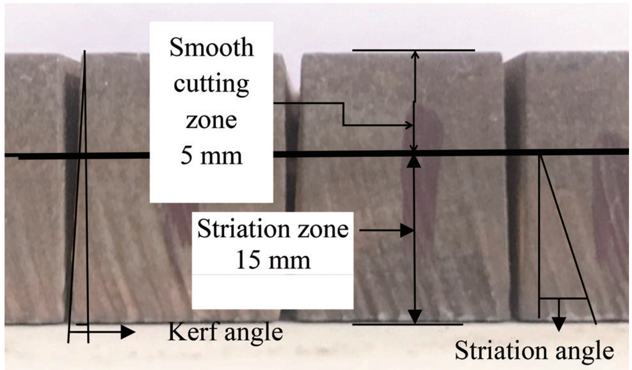

Figure 13. Kerf angle and striation angle of work piece using Garnet

Discussion: Abrasive 1 Garnet

It is observed (refer Table 10) that surface finish obtained poor as compared with other two abrasives, width of smooth cutting zone is very less (5 mm) as compared to other two pieces (refer Figure 13) Striation angle is large as compared with other two pieces (refer Figure 21). Striation angle is angle between mark of striation and vertical.

The R square values of both MRR and Kerf Angle are nearer to 100% this indicates that the obtained results are optimal. (Abrasive I kerf angle (R_{sq}=72.90%.MRR R_{sq}=96.21%)

Abrasive 2 Brown Fused Alumina

Table 13. Results obtained with brown Fused alumina

NTS mm/min	AFR kg/min	SOD mm	Kerf Angle degree	MRR mm^3/min
40	250	2	0.846	995.6
40	300	3	0.971	956.8
40	350	4	0.865	996.8
50	250	3	0.948	1186
50	300	4	0.930	1181
50	350	2	1.071	1191
60	250	4	0.797	1565.4
60	300	2	0.850	1486.8
60	350	3	0.966	1457.4

 DOI: https://doi.org/10.30564/omms.v1i1.892

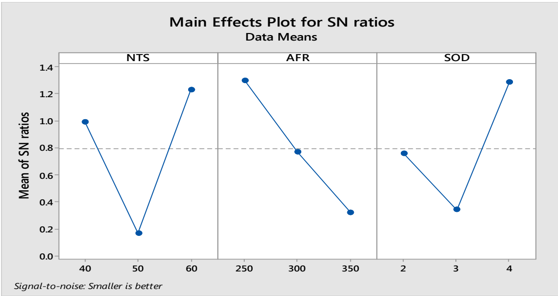

Figure 14. Main effect plot for SN ratio Kerf angle vs factors using Brown fused alumina

From S/N ratio of kerf angle optimum values are NTS 60 mm/min, AFR 250 kg/min, SOD 4 mm.

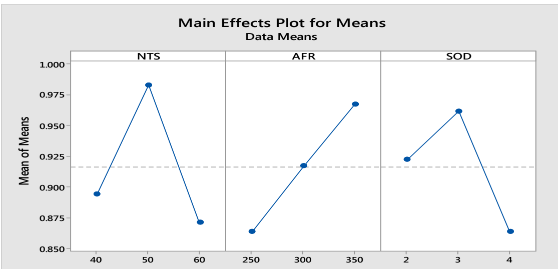

Figure 15. Main effect Plot for Means Kerf angle vs factors using Brown fused alumina

From data of plot for means kerf angle increases linearly with AFR, and kerf angle increases up to middle value and then falls in case of NTS and SOD.

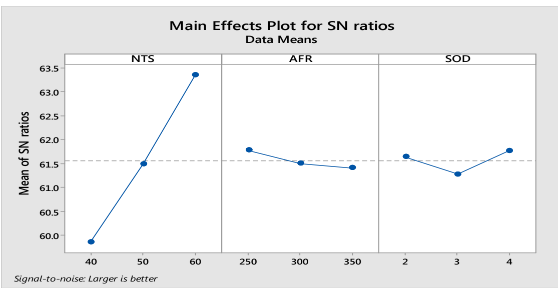

Figure 16. Main effect plot for SN ratio MRRvs Factors using Brown fused alumina

From S/N ratio of MRR optimal values are NTS 60 mm/min, AFR 250 kg/min, SOD 4mm

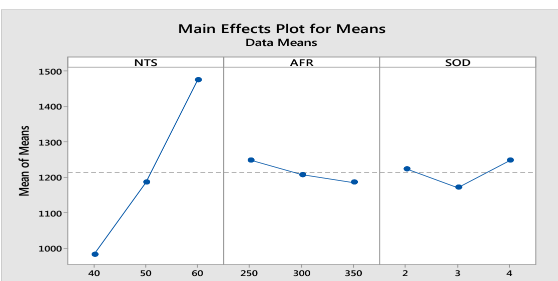

Figure 17. Main effect Plot for Means MRR vs factors using Brown fused alumina

From data of plot for means MRR increases linearly with NTS MRR not shown any considerable effect with AFR and SOD

Table 14. ANOVA Abrasive 2 kerf angle

Source	Rank	Contribution	FValue	P Value
NTS mm/min	1	36.97	4.05	0.198
AFR kg/min	2	28.93	3.11	0.243
SOD mm	3	25.51	2.8	0.263

From ANOVA test NTS (contribution 36.97% highest F value 4.05) is significant factor followed by AFR (28.39%) ,SOD (25.51%).

Table 15. Response for SN ratio abrasive 2 kerf angle

Level	NTS mm/min	AFR kg/min	SOD mm
1	0.9893	1.2958	0.7561
2	0.1661	0.7659	0.34
3	1.2276	0.3214	1.287
Delta	1.0615	0.9743	0.947
Rank	1	2	3

Table 16. ANOVA abrasive 2 MRR

Source	Rank	Contribution	F Value	P Value
NTS mm/min	1	94.76	74.46	0.013
AFR kg/min	3	1.58	1.24	0.447
SOD mm	2	2.39	1.88	0.348

From ANOVA test NTS (contribution 94.76% highest F value 74.46) is dominating factor followed by SOD (2.39%) AFR (1.58%).

Table 17. Response for SN ratio abrasive 2MRR

Level	NTS Mm/min	AFR kg/min	SOD mm
1	59.85	61.78	61.64
2	61.48	61.5	61.28
3	63.36	61.41	61.77
Delta	3.51	0.37	0.49
Rank	1	3	2

Table 18. Validation experiment using brown fused alumina

Optimum Parameters		Predicted optimum value using optimum setting Error	Actual value produced
NTS	60 mm/min	Kerf angle 0.792 degree	Kerf angle 0.797 degree
AFR	250 kg/min		
SOD	4 mm		Error = 0.627%

  DOI: https://doi.org/10.30564/omms.v1i1.892

NTS	60 mm/min	MRR 1344 mm3/min	MRR 1565.4mm3/min
AFR	250 kg/min		
SOD	4mm		Error = 14.14%

The validation experiment were conducted using the optimum combination of machining parameters obtained and results were compared and error was found as tabulated in Table 18.

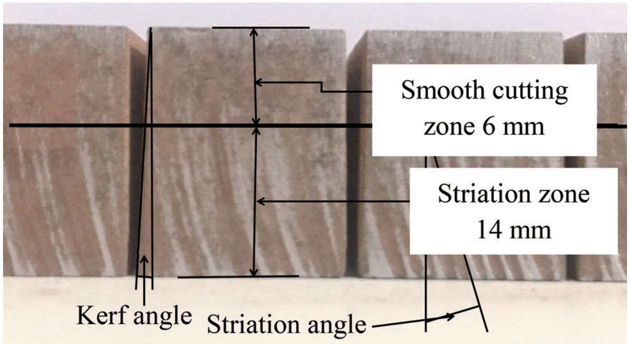

Figure 18. Kerf angle and striation angle of work piece using Brown fused alumina

Discussion: Abrasive II Brown Fused Alumina

It is observed (refer Table 10) that surface finish obtained moderate as compared with other two abrasives, width of smooth cutting zone is more than garnet and less than white aluminum oxide (6mm, refer Figure 18) Striation angle is large when compared with garnet (refer Figure 18).

The R square values of both MRR and kerf angle are nearer to 100% this indicates that results were obtained are optimal. Abrasive II kerf angle R_{sq}=90.88%, MRR_{sq}=98.73 .it can be observed (refer Table 10) that surface finish obtained moderate (refer Figure 24 and Figure 18).

Abrasive 3 White Aluminum Oxide

Table 19. Results obtained with White Aluminum Oxide

NTS mm/min	AFR kg/min	SOD mm	Kerf Angle degree	MRR mm^3/min
40	250	2	1.079	1058.4
40	300	3	0.995	1011.2
40	350	4	0.737	1054.4
50	250	3	1.264	1319.5
50	300	4	1.155	1262.5
50	350	2	1.084	1296.5
60	250	4	1.297	1582.2
60	300	2	1.463	1565.4
60	350	3	1.3	1575.6

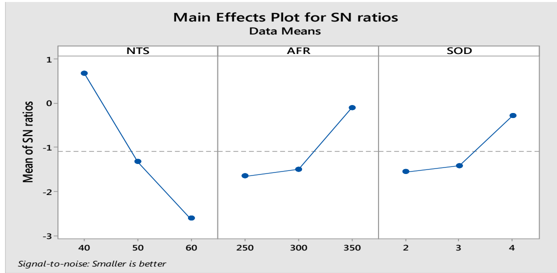

Figure 19. Main effect plot for SN ratio Kerf angle vs Factors using White aluminum oxide

From S/N ratio of kerf angle optimum values are NTS 40 mm/min, AFR 350 kg/min, SOD 4 mm.

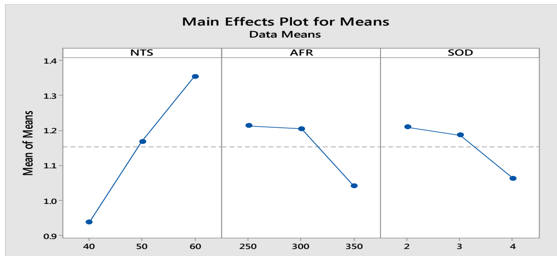

Figure 20. Main effect Plot for Means Kerf angle vs factors using White aluminum oxide

From data of plot for means kerf angle increases linearly with NTS kerf angle continuously decreases with increase in AFR and SOD.

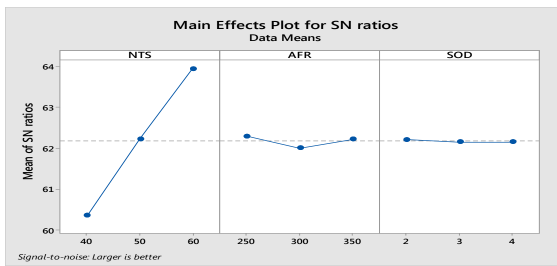

Figure 21. Main effect plot for SN ratio MRR vs factors using White aluminum oxide

From S/N ratio of MRR optimum values are NTS 60 mm/min, AFR 250 kg/min, SOD 2 mm.

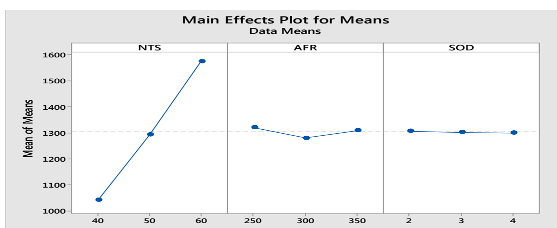

Figure 22. Main effect Plot for Means MRR vs factors using White aluminum oxide

From data of plot for means MRR increases linearly with NTS, MRR not shown any considerable effect with AFR and SOD.

DOI: https://doi.org/10.30564/omms.v1i1.892

Table 20. ANOVA Abrasive 3 Kerf Angle

Source	Rank	Contribution	F Value	P Value
NTS mm/min	1	72.70	62.46	0.016
AFR kg/min	2	15.85	13.62	0.068
SOD mm	3	10.29	8.84	0.102

From ANOVA NTS (contribution 72.70 % highest F value 62.46) is most significant factor followed by SOD (10.29%) AFR (15.85%).

Table 21. Response for SN ratio abrasive 3Kerf Angle

Level	NTS mm/min	AFR kg/min	SOD mm
1	0.6779	-1.6514	-1.5553
2	-1.3291	-1.5043	-1.4234
3	-2.6142	-0.1096	-0.2866
Delta	3.2921	1.5418	1.2687
Rank	1	2	3

Table 22. ANOVA abrasive 3MRR

Source	Rank	Contribution	F Value	P Value
NTS mm/min	1	99.27	889.82	0.001
AFR kg/min	2	0.61	5.42	0.156
SOD mm	3	0.02	0.16	0.861

From ANOVA NTS (contribution 99.27% highest F value 889.82) Is dominating factor followed by SOD (.02%) AFR (.61%).

Table 23. Response for SN ratio abrasive 3 MRR

Level	NTS mm/min	AFR kg/min	SOD mm
1	60.35	62.3	62.21
2	62.23	62	62.15
3	63.94	62.22	62.16
Delta	3.59	0.29	0.06
Rank	1	2	3

The validation experiment were conducted using the optimum combination of machining parameters obtained and results were compared and error was found as tabulated in Table 24

Table 24. Validation experiment using White Aluminum Oxide

Optimum Parameters		Predicted optimum value using optimum setting Error	Actual value produced
NTS	40 m/min	Kerf angle 0.670degree	Kerf angle 0.737degree
AFR	350 g/min		
SOD	4 mm		Error =0.090%
NTS	60 mm/min	MRR 1401mm3/min	MRR 1582.2mm^3/min
AFR	250 kg/min		
SOD	2mm		Error =11.45%

The validation experiment were conducted using the optimum combination of machining parameters obtained and results were compared and error was found as tabulated in Table 24

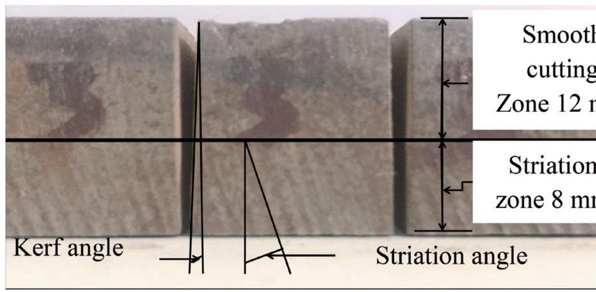

Figure 23. Kerf angle and striation angle of work piece using White aluminum oxide

Discussion: Abrasive III White Aluminum Oxide

It is observed (refer Table 10) that surface finish obtained good as compared with other two abrasives, width of smooth cutting zone is widest (12 mm) as compared to other two pieces refer Figure 24. Striation angle is small as compared with other two pieces (refer Figure 23). The R square values of both MRR and kerf angle are nearer to 100% this indicates that results were obtained are optimal, Abrasive III kerf angle R_{sq}=99.84% MRR R_{sq}=99.89%. it can be observed(refer Table 10) that surface finish obtained good as compared with other two Abrasives.(Figure 23 and Figure 24).

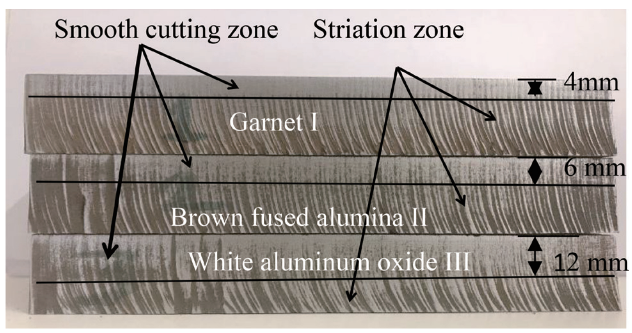

Figure 24. Comparative surface finish of work piece using abrasive I, II and III

4. Discussion

It is observed that MRR increases linearly with Nozzle transverse speed with all three different abrasives but it is not in case of kerf angle. Kerf angle increases linearly with NTS in case of Garnet and White aluminum oxide, but it increases up to middle value and then fallsin case of Brown fused alumina. It is further observed that higher

DOI: https://doi.org/10.30564/omms.v1i1.892

range of MRR is achieved in case of White Aluminum Oxide (1011.2 to1582.2) which is near to ideal MRR of 1320 mm/min. If an average of MRR is taken we get values for Abrasive I (1007.1) Abrasive II (1228) Abrasive III (1302) very near to ideal value 1320 and kerf angle for Abrasive I is 1.257 Abrasive III is 1.152 and for Abrasive II is 0.80, which is very less near to ideal 0 degree.

In case of MRR, NTS is dominating F values (larger F value indicates that there is big impact of particular process a parameter on the performance characteristics) and more than 90 % contribution value is validating earlier researcher's results. Results obtained by Taguchi in terms of parameters with their rankings confirm to the rankings given by ANOVA. R_{Sq}. values nearly equal to 100 % indicating the results are optimal. .(abrasive I kerf angle Rsq =82.56%.MRR Rsq=98.515%,abrasive II kerf angle Rsq=90.88%,MRR Rsq=98.73 abrasive III kerf angle Rsq=99.84% MRR Rsq=99.89%).

White Aluminum Oxide shows less Ra value see Table 6, widest smooth cutting zone see Fig 24, small striation angle see Fig 23 as compared with other two work pieces

The validation experiment was conducted using the optimum combination of machining parameters obtained and results were compared for each piece cut with White Aluminum oxide, Brown fused alumina and Garnet.(refer Table 12, 18 and 24)

Future scope is summarized as follows

1) The effect of both abrasives Brown fused alumina and White aluminum oxide on the wear of nozzle can be studied. In the present study we have observed Brown fused alumina have shown a significant effect on nozzle wear.

2) Abrasive size, nozzle length, orifice diameter can also be considered as input parameters

3) More research work is required to replace Garnet as abrasive material to achieve competitive results using AWJM compared with other nonconventional machining processes regarding surface finish and MRR.

5. Conclusion

The application of the Taguchi method and ANOVA General linear method in the analysis of experimental result yields the following conclusion

a) It is observed that MRR increases linearly with Nozzle transverse speed in all three cases (refer Figure 12, 17 and 22). Kerf angle also increases linearly except in case of abrasive II.

b) It is observed that we get a higher range of MRR in case of White Aluminum Oxide which is near to ideal MRR of 1320 mm/min. If an average of MRR is taken we get values for Abrasive III very near to ideal value (1320) but with concerned to kerf angle Abrasive II near to ideal (0 degree)

c) In case of MRR NTS is dominating F values and more than 90 % contribution value validating previous researcher's results

d) Results obtained by Taguchi in terms of parameters with their rankings confirm to the rankings given by ANOVA.

e) R_{Sq}. values nearly equal to 100 % indicate results are optimal.

f) It is observed that the width of the smooth cutting zone of each work piece,(4mm,6 mm and 12 mm for Garnet ,brown fused alumina and White aluminum oxide respectively) a work piece using white aluminum oxide shows widest smooth cutting zone and lowest striation zone as compared with the other two work pieces (refer Figure 24)

g) The validation experiment was conducted using the optimum combination of machining parameters obtained and results were compared for each piece very little error found

h) It is observed that work piece using White Aluminum Oxide) shows less Ra value (refer Table 6), widest smooth cutting zone (refer Figure 24), small striation angle (refer Figure 23) as compared with other two work pieces. It can be concluded that white aluminum oxide produces parts with good surface finish, good MRR, less kerf angle as compared with Garnet hence White Aluminum Oxide can be used in place of Garnet, which is presently used by industry.

Acknowledgements

The author and his team would like to thank Mr. BhausahebKandre for allowing them to carry out experimentation in his premises and utilize resources at SASA Engineering, Bhosari, Pune.

References

[1] Vishal Gupta, P. M. Pandey, Mohinder Pal Garg, Rajesh Khanna, and N. K. Batra. "Minimization of Kerf Taper Angle and Kerf Width Using Taguchi's Method in Abrasive Water Jet Machining of Marble."Procedia Materials Science6 (2014): 140-149.

[2] Karakurt, I., Aydin, G., Aydiner, K., "A machinability study of granite using abrasive water jet cutting technology", Gazi University Journal of Science 24(1), 143-151, 2011.

[3] Borkowski J.: "Materials cutting with abrasive suspension jet using BorJet system" International Symposium on Unconventional Hydro Jetting Technolo-

gies, Koszalin, 2007,pp. 129-136.

[4] P. P. Badgujar ,M.G.Rathi "Abrasive Water jet Machining-A State of Art" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. VI (May- Jun. 2014), PP 59-64

[5] D siddha reddy, Asesukumar,MsreenivasaRao"Parametric optimization of abrasive water jet machining of Inconol 800 H using Taguchi methodology" Universal Journal of Mechanical Engineering Vol. 2(5), pp. 158 - 162 DOI: 10.13189/ujme.2014.020502

[6] LeeladharNagdeve, VedanshChaturvedi, JyotiVimal "Implementation Of Taguchi Approach For Optimization Of Abrasive Water Jet Machining Process Parameters" International Journal Of Instrumentation, Control And Automation (Ijica) Issn: 2231-1890, Vol-1 Iss-3, 4, 2012

[7] KamleshH.Thakkar,.VipulM.Prajapati,ShreyashA. Thakkar "A Machinability Study of Mild Steel using Abrasive Water Jet Machining Technology" International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 3, May-Jun 2013,

[8] Akkurt, Adnan, Mustafa Kemal Kulekci, UlviSeker, and FevziErcan. "Effect of feed rate on surface roughness in abrasive water jet cutting applications ."Journal of Materials Processing Technology 147, no. 3 (2004): 389-396.

[9] Momber, Andreas W., and Radovan Kovacevic. Principles of abrasive water jet machining. Springer Science & Business Media, 2012.

[10] Kulekci, Mustafa Kemal. "Processes and apparatus developments in industrial water jet applications." International Journal of Machine Tools and Manufacture 42, no. 12 (2002): 1297-1306.

[11] Akkurt, Adnan. "Cut front geometry characterization in cutting applications of brass with abrasive water jet." Journal of Materials Engineering and Performance 19, no. 4 (2010): 599-606.

[12] Selvan, M. ChithiraiPon, and N. MohanaSundaraRaju. "Analysis of surface roughness in abrasive waterjet cutting of cast-iron." International Journal of Science, Environment and Technology 1, no. 3 (2012): 174-182.

[13] Ay, Mustafa, UlaşÇaydaş, and AhmetHascalik. "Effect of traverse speed on abrasive water jet machining of age hardened Inconel 718 nickel-based super alloy. "Materials and Manufacturing Processes 25, no. 10 (2010): 1160-1165.

[14] Shipway, P. H., G. Fowler, and I. R. Pashby. "Characteristics of the surface of a titanium alloy following milling with abrasive water jets." Wear 258, no. 1 (2005): 123-132.

[15] Hascalik, Ahmet, UlaşÇaydaş, and HakanGürün. "Effect of traverse speed on abrasive water jet machining of Ti-6Al-4Valloy."Materials & Design 28, no. 6 (2007): 1953-1957.

[16] Aultrin, KS Jai, and M. DevAnand. "Optimization of Machining Parameters in AWJM Process for a Copper Iron Alloy Using RSM and Regression Analysis."

[17] Fowler, G., P. H. Shipway, and I. R. Pashby. "A technical note on grit embedment following abrasive water-jet milling of a titanium alloy. "Journal of materials processing technology 159, no. 3 (2005): 356-368.

[18] Iqbal, Asif, Naeem U. Dar, and GhulamHussain. "Optimization of abrasive water jet cutting of ductile materials. "Journal ofWuhan University of Technology-Mater. Sci. Ed. 26, no. 1 (2011): 88-92.

[19] Maros, Zsolt. "Taper of Cut at Abrasive Water jet Cutting of an Aluminum Alloy. "Journal of Production Processes and Systems 6, no. 1 (2012): 55-60.

[20] Li, Huaizhong, and Jun Wang. "An experimental study of abrasive water jet machining of Ti-6Al-4V."The International Journal of Advanced Manufacturing Technology (2015): 1-9.

[21] Escobar-Palafox, G. A., R. S. Gault, and K. Ridgway. "Characterization of abrasive water-jet process for pocket milling in Inconel 718." Procedia CIRP 1 (2012): 404-408.

[22] Khan, Ahsan Ali, and M. M. Haque. "Performance of different abrasive materials during abrasive water jet machining of glass. "Journal of materials processing technology 191, no. 1 (2007): 404-407.

[23] Aich, Ushasta, Simul Banerjee, AsishBandyopadhyay, and Probal Kumar Das. "Abrasive water jet cutting of borosilicate glass."Procedia Materials Science 6 (2014): 775-785.

[24] Matsumura, T., T. Muramatsu, and S. Fueki. "Abrasive water jet machining of glass with stagnation effect."CIRP Annals-Manufacturing Technology 60, no. 1 (2011): 355-358.

[25] Xu, S., and J. Wang. "A study of abrasive waterjet cutting of alumina ceramics with controlled nozzle oscillation." The International Journal of Advanced Manufacturing Technology 27, no. 7-8 (2006): 693-702.

[26] Selvan, M. ChithiraiPon, and N. MohanaSundaraRaju. "Effects of Process Parameters & Depth of Cut Model for AbrasiveWaterjet Cutting of Ceramics." parameters3: 1-8.

[27] Azmir, M. A., A. K. Ahsan, and A. Rahmah. "Effect of abrasive water jet machining parameters on aramid fiber reinforced plastics composite. "International Journal of Material Forming 2, no. 1 (2009): 37-44.

  DOI: https://doi.org/10.30564/omms.v1i1.892