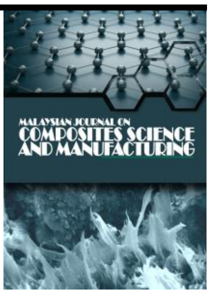
Penerbit
Akademia Baru

Malaysian Journal on Composites Science
and Manufacturing

Journal homepage:
https://www.akademiabaru.com/submit/index.php/mjcsm/
ISSN: 2716-6945



# Taguchi Method-Based Optimization of Single-Pass Abrasive Waterjet Cutting of Thick Aluminium

Hanizam Hashim[1,*], Noraiham Mohamad[1], Nor Bahiyah Baba[2], Bobby Umroh[3]

[1] Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal Melaka 76100, Malaysia.
[2] Faculty of Engineering Technology, University College TATI (UC TATI), Teluk Kalong, Kemaman 24000, Terengganu.
[3] Department of Mechanical Engineering, Faculty of Engineering, Universitas Medan Area, Indonesia.

**ARTICLE INFO**

***Article history:***
Received 10 February 2025
Received in revised form 21 March 2025
Accepted 25 March 2025
Available online 30 March 2025

***Keywords:***

Abrasive Waterjet Machining, Taguchi Method, Process Optimization, Traverse Speed, Waterjet Pressure, Stand-Off Distance

**ABSTRACT**

Cutting force attenuation in AWJ induces surface defects (high Ra, large Ɵ°) in metals and delamination in composites, especially in thick sections that limiting industrial adoption and requiring post-processing. A robust Taguchi experimental design was employed to optimize AWJ cutting parameters to minimize these issues when cutting thick aluminium blocks. An L8 orthogonal array with three factors; waterjet pressure (WP), stand-off distance (SOD), and traverse speed (TS), each at two levels, was used and analyzed via Minitab software. Other parameters remained constant: nozzle diameter (1.0 mm), abrasive size (80 mesh), and abrasive flow rate (0.3 kg/min). Traverse speed was found to be the most critical factor affecting Ra and Ɵ°, though waterjet pressure and stand-off distance also had significant impacts. The optimal parameters, higher waterjet pressure (315 MPa), lower traverse speed (38 mm/min), and lower stand-off distance (3 mm), yielded the best results for both Ra (4.2 µm) and Ɵ° (1.24°). In conclusion, the interaction of optimized AWJ parameters enhances kinetic energy and momentum transfer, improving material removal efficiency and cutting surface quality. The study systematically evaluates critical abrasive waterjet parameters to optimize cutting strategies, demonstrating applicability for thick aluminium and diverse material types.

## 1. Introduction

Aluminium and its alloys are extensively used in many automotive and aerospace industries due to their excellent strength-to-weight properties. The lightweight nature of aluminium is crucial for reducing greenhouse gas emissions and promoting a sustainable environment. Additionally, recycling aluminium is much simpler than recycling other common metals like steel, which is another critical factor in reducing the carbon footprint [1-2]. Despite these advantages, achieving the closest cutting

---

[*] *Corresponding author.*
*E-mail address: hanizam@utem.edu.my (Hanizam Hashim)*
*E-mail of co-authors: noraiham@utem.edu.my, bahiyah@uctati.edu.my, bobbyumroh@staff.uma.ac.id*

https://doi.org/10.37934/mjcsm.16.1.6068

tolerances for fitting and other applications remains a significant challenge. Popular non-conventional methods such as laser and electrical discharge machining can lead to thermal damage, including heat-affected zones that introduce internal stress, recast layers, and shorten product life [3]. These adverse impacts can be mitigated by using abrasive water jet (AWJ) machining technology [4-6].

AWJ machining uses high-velocity water entrained with abrasive particles to cut a wide range of materials, including composites [7-8]. It offers numerous benefits over other cutting technologies, such as no thermal distortion, high machining versatility, high flexibility, and low cutting forces [9-11]. The system employs an intensifier technique to pump water to extremely high pressures, typically between 30,000 and 90,000 psi, which passes through an aperture to generate a high-velocity water jet. As the water jet passes through a mixing chamber, it creates a vacuum that pulls in abrasive particles through a separate entrance, transferring high momentum of water and abrasive out of a narrow nozzle to the workpiece [12].

Surface quality and taper angle are crucial factors in the precise machining of materials using AWJ [13-14]. Surface quality in AWJ refers to the uniformity, irregularity, and integrity of the cut surface. These flaws not only hinder the functional performance of the machinesd components but also increase costs by necessitating additional surface improvement operations. Additionally, the taper angle, which refers to the gradual change in cutting kerf width from the start to the exit of the cut, is critical. Excessive taper angle results in dimensional inaccuracies, risking the functionality and fitting of machined parts, especially in applications requiring high precision. Achieving a low and consistent taper angle is essential for maintaining the dimensional accuracy and geometric precision of the cut surfaces.

The Taguchi method is a reliable, simple, and cost-effective technique widely applied in industries to optimize AWJ parameters [15-16]. This technique involves an orthogonal array experiment to establish the actual scatter of in-control and beyond-control values, known as signal (S) and noise (N), respectively. The ratio of S/N is used to obtain the optimal parameter settings depending on the study's aim, whether "bigger is better," "smaller is better," or "nominal is best" [17]. Joel and Jeyapoovan [18] combined Grey Relation Analysis and the Taguchi method to optimize the multi-responses of abrasive feed rate (AFR), stand-off distance (SOD), and traverse speed (TS) of AWJ parameters on an AA7075 aluminium alloy. The smallest surface roughness was obtained with 250 g/min (AFR), 3 mm (SOD), and 36 mm/min (TS). Similarly, Gowthama *et al.* [19] conducted a Taguchi experiment on these factors for Al7071 aluminium alloy surface roughness, finding that TS was the most influential factor, followed by AFR, with SOD having the least impact.

Therefore, it is important to investigate and resolve the root cause factors that contribute to poor surface quality and taper angle in single-pass AWJ [20-22]. Several process parameters, such as abrasive flow rate, stand-off distance, traverse speed, and orifice diameter, influence the quality of these characteristics [23-24]. According to a statistical finding by Llanto *et al.* [25], based on studies conducted by researchers worldwide from 2017 to 2020, 27% concluded that traverse speed is the most influential input parameter in the AWJ cutting process, followed by waterjet pressure, abrasive mass flow rate, and stand-off distance, with 22%, 20%, and 19% contributions, respectively. Although few studies have considered abrasive size, nozzle and orifice diameter, abrasive material, and jet impact angle, the effects of these input parameters cannot be justified due to limited attention from researchers and infrequent use in experimental studies [26-27].

This study investigates three key factors influencing surface quality and taper angle in single-pass abrasive waterjet (AWJ) machining of aluminium blocks: traverse speed, waterjet pressure (WP), and stand-off distance. A Taguchi L8 orthogonal array design of experiments (DoE) was employed for process optimization. The results indicate that the optimal parameter combination consists of high waterjet pressure coupled with low traverse speed and low stand-off distance.

## 2. Methodology

### *2.1 Material and equipment*

This study selected a pure aluminium block with dimensions of 32 mm in thickness and 100 mm in width as the primary material, as illustrated in Figure 1. The choice of aluminium was due to its widespread industrial applications and relevance in cutting industries. A mineral abrasive with a mesh size of 80, derived from almandine garnet, was utilized in the Abrasive Water Jet (AWJ) cutting process. Almandine garnet was chosen for its hardness and effectiveness in cutting a variety of materials, including steel, aluminium, and marble.

The AWJ cutting operations were performed using a Flow Mach 2 waterjet machine, depicted in Figure 2. This machine is equipped with a fixed cutting nozzle of 1.0 mm in diameter, ensuring precision in the cutting process. The Flow Mach 2 is known for its reliability and accuracy in industrial cutting applications.

**Fig. 1.** Aluminium block

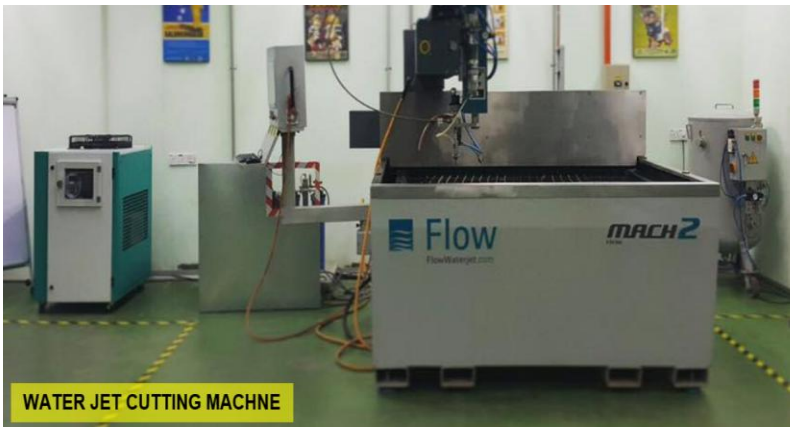


**Fig. 2.** Abrasive waterjet machine

### *2.2 Taguchi method: Design of experiment*

This research employed Taguchi's L8 orthogonal array, consisting of 8 experiments with 3 factors at 2 levels each. The experiments were designed and analyzed using Minitab software. The signal-to-noise (S/N) ratio was utilized to optimize the outputs, aiming for smaller, better results.

The variable factors considered in the experiments were waterjet pressure (WP), stand-off distance (SOD), and traverse speed (TS), each at low and high levels as detailed in Table 1. Other parameters were kept constant, including the nozzle diameter (1.0 mm), abrasive size (80 mesh), and abrasive flow rate (0.3 kg/min) [28]. Each experiment involved a series of straight cuts (90 mm) on the same aluminium block. The setup for the Taguchi L8 experiments is shown in Table 2.

**Table 1**
Variable factors at low and high parameters setting

| Factor | Waterjet pressure, MPa | Transverse speed, mm/min | Stand-off distance, mm |
|---|---|---|---|
| High | 315 | 76 | 6 |
| Low | 245 | 38 | 3 |

**Table 2**
Taguchi L8 orthogonal array

| Exp. No. | Waterjet pressure, MPa | Transverse speed, mm/min | Stand-off distance, mm |
|---|---|---|---|
| 1 | 245 | 38 | 3 |
| 2 | 245 | 38 | 6 |
| 3 | 245 | 76 | 3 |
| 4 | 245 | 76 | 6 |
| 5 | 315 | 38 | 3 |
| 6 | 315 | 38 | 6 |
| 7 | 315 | 76 | 3 |
| 8 | 315 | 76 | 6 |

### *2.3 Testing and Analysis*

The surface roughness (Ra) of the cutting surface was evaluated using a Mitutoyo surface roughness analyzer, following the ISO 4287:1997 standard. The average Ra value was calculated from 10 measurements for each experiment.

Additionally, the cutting taper angles (θ°) were measured using a Mitutoyo vertical optical comparator model 20-4600, as shown in Figure 3. The average value of 5 taper angle measurements was used for each experiment.

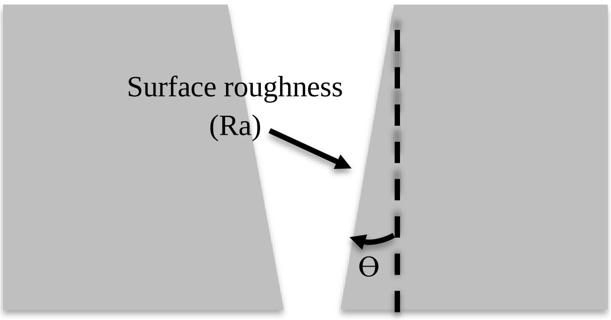


**Fig. 3.** Surface roughness (Ra) and taper angle (ϴ°) measurements

## 3. Results

### 3.1 Analysis of Taguchi on surface roughness

The $L_8$ experimental data reveal that Exp. 5 (high WP: 315 MPa, low TS: 38 mm/min, low SOD: 3 mm) yields the lowest average Ra (4.22 µm), whereas Exp. 8 (high WP: 315 MPa, high TS: 76 mm/min, high SOD: 6 mm) results in the highest Ra (5.14 µm), as illustrated in Table 3 and Figure 4. This contrast highlights the significant role of traverse speed (TS) and stand-off distance (SOD) in surface roughness, despite both experiments sharing the same high waterjet pressure (WP). The 21.8% increase in Ra for Exp. 8 suggests that higher TS and SOD exacerbate striations and particle embedment, while the lower TS and SOD in Exp. 5 promote smoother cutting due to prolonged abrasive interaction and reduced jet dispersion.

**Table 3**
Surface roughness, Ra (um) at 10 locations on each sample

| Data | Exp. No. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 4.81 | 4.84 | 4.81 | 4.94 | 4.28 | 4.83 | 5.31 | 5.28 |
| 2 | 5.05 | 5.59 | 4.20 | 4.40 | 3.72 | 4.68 | 5.22 | 4.11 |
| 3 | 5.08 | 4.71 | 4.87 | 5.73 | 3.60 | 5.08 | 5.03 | 5.89 |
| 4 | 5.12 | 5.50 | 4.89 | 5.39 | 4.13 | 5.18 | 4.99 | 4.59 |
| 5 | 5.01 | 5.17 | 4.79 | 4.98 | 4.71 | 4.37 | 4.86 | 4.72 |
| 6 | 4.91 | 4.86 | 4.26 | 6.30 | 4.11 | 4.05 | 4.41 | 5.51 |
| 7 | 4.64 | 4.92 | 5.08 | 5.01 | 4.60 | 4.69 | 5.17 | 5.18 |
| 8 | 5.41 | 4.80 | 5.12 | 4.90 | 4.55 | 4.65 | 5.34 | 4.81 |
| 9 | 5.20 | 4.65 | 4.42 | 4.91 | 4.24 | 4.08 | 4.62 | 6.07 |
| 10 | 4.80 | 4.70 | 5.34 | 5.06 | 4.23 | 4.88 | 4.90 | 5.20 |
| Ave. | 5.00 | 4.97 | 4.78 | 5.16 | 4.22 | 4.65 | 4.99 | 5.14 |

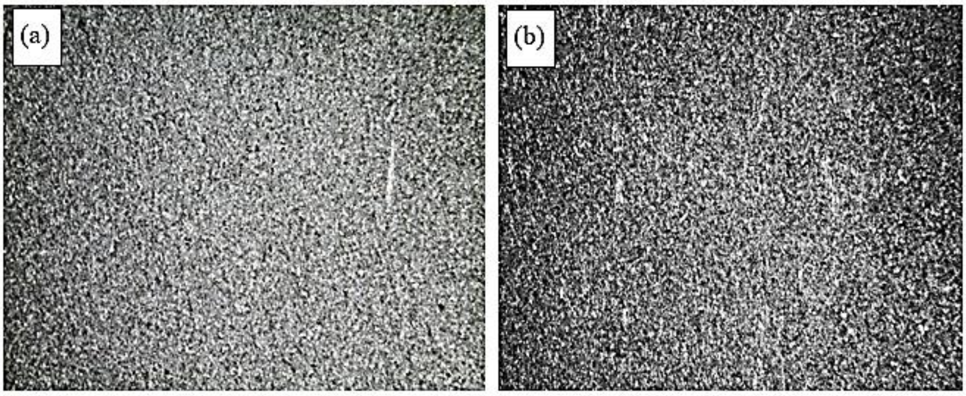


**Fig. 4.** Surface roughness of (a) Exp.5 and (b) Exp. 8

Taguchi analysis shows all factors in the studies significantly impact the cutting surface roughness. The traverse speed (TS) has the most significant impact. Moreover, the stand-off distance (SOD) and waterjet pressure (WP) have an almost similar impact on Ra, as shown in Figure 5. The Ra decreases with TS decreased as a slower speed gives the waterjet more time to remove material efficiently and provide a smoother surface. Likewise, the Ra increases as SOD increases; at higher SOD, an air resistance causes the waterjet pressure and velocity to drop significantly. Hence, its kinetic force is reduced and provides less impact to remove material from the cutting area as compared with a lower SOD [29]. This observation agrees with the WP impact in which Ra improves at higher WP, resulting in a smoother cutting surface. Slower traverse rates enable the water jet more time for the water and abrasive particulates to remove material efficiently and provide a smoother surface. However, excessively slow traverse velocities may result in excessive attrition or material deformation, resulting in a rougher surface. On the other hand, extremely high traverse speeds can affect the cutting action, resulting in poor surface quality and increased irregularity.

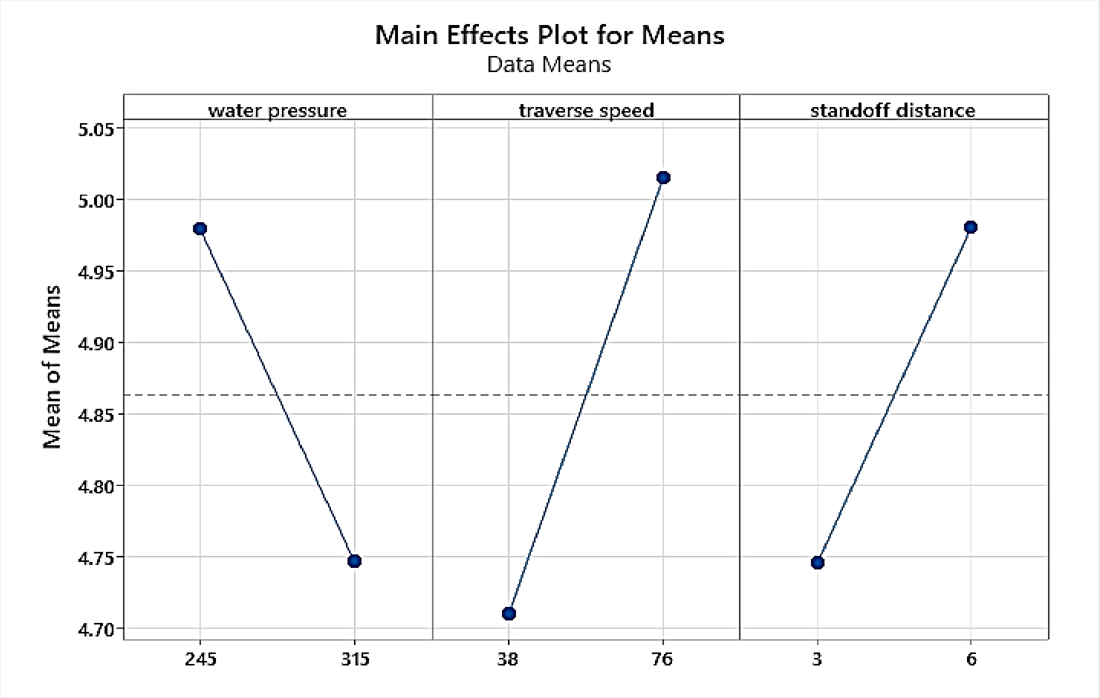


**Fig. 5.** Main effects plot for means of Ra

### *3.2 Analysis of Taguchi on cutting taper angle*

The taper angle in abrasive water jet cutting greatly impacts fitting machined parts such as gears. Table 4 shows the results of average taper angles based on the Taguchi L8 experiments. Again, Exp. 5 has produced the smallest average taper angle (ϴ°) of 1.24°. On the other hand, the Exp. 3 with low WP (245 MPa), high TS (76 mm/min) and low SOD (3 mm) have given the largest ϴ° of 1.55°.

**Table 4**
Taper angle (ϴ°)

| Data | Exp. No. (°) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 1.14 | 1.55 | 1.48 | 1.26 | 1.03 | 1.27 | 1.26 | 1.18 |
| 2 | 1.18 | 1.11 | 1.50 | 1.10 | 1.05 | 1.41 | 1.37 | 1.38 |
| 3 | 1.23 | 1.37 | 1.43 | 1.51 | 1.06 | 1.29 | 1.40 | 1.36 |
| 4 | 1.27 | 1.43 | 1.55 | 1.32 | 1.24 | 1.34 | 1.43 | 1.25 |
| 5 | 1.33 | 1.27 | 1.45 | 1.40 | 1.26 | 1.20 | 1.35 | 1.27 |
| Ave. | 1.23 | 1.35 | 1.48 | 1.32 | 1.13 | 1.30 | 1.36 | 1.29 |

Taguchi's analysis of the kerf taper angle shows a similar trend to the cutting surface roughness. The traverse speed (TS) has the most significant impact. However, this time the waterjet pressure (WP) has more impact as compared with the stand-off distance (SOD), as shown in Figure 6.

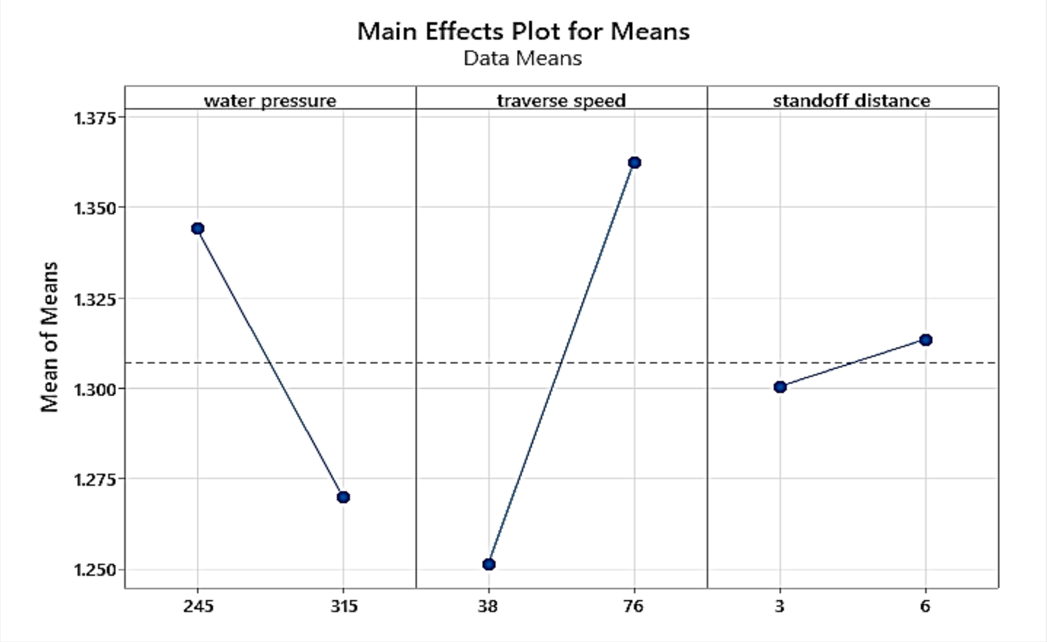


**Fig. 6.** Main effects plot for means of taper angle (ϴ°)

Lower traverse speed typically produced smoother cuts with decreased taper angles. This is because slower traverse rates give abrasive particulates more time to erode the material uniformly. Unlike at higher traverse velocities, the cutting action becomes less precise and not concentrated, resulting in greater taper angles. When water pressure is increased, the jet kinetic energy increases, leading to a high momentum transfer of the abrasive and a decrease in kerf taper angle [30]. The kerf angle generally tends to increase as the stand-off distance increases. As the distance between the nozzle and the part's surface increases, the stream of water and abrasive particulates spreads out and disperses more.

## 4. Conclusions

A robust Taguchi $L_8$ orthogonal array was employed to optimize abrasive waterjet cutting parameters for surface quality (Ra) and kerf angle (ϴ°) in aluminium blocks. Traverse speed emerged as the most influential factor, accounting for the greatest variance in both surface finish and taper angle. While waterjet pressure and stand-off distance exhibited comparatively lesser impacts on Ra and ϴ°, their contributions remained statistically significant. The optimal results were achieved in Exp. 5, which combined high waterjet pressure (315 MPa), low traverse speed (38 mm/min), and low stand-off distance (3 mm). This configuration enhances cutting precision by maximizing the kinetic energy of water molecules and abrasive particles, thereby promoting efficient material removal with minimal surface irregularities. These findings establish a foundational framework for future optimization and advancement of abrasive waterjet cutting processes. These findings provide actionable insights for manufacturing applications requiring high-precision aluminium cutting, particularly in aerospace and automotive components where surface integrity is critical. The established parameter-property relationships serve as a foundation for future research in adaptive AWJ process control and multi-objective optimization.

## Acknowledgment

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for the raw materials and facilities used to conduct the experimental work.

## References

[1] E. Vidales, N. Cuadrado, E. Garcia-Llamas, J.T. Garitano, I. Aseguinolaza, M. Carranza, M. Vilaseca and G. Ramirez, “Surface Roughness Analysis for Improving Punching Tools Performance of 5754 Aluminium Alloy,” Wear 524-525, (2023): 204743. https://doi.org/10.1016/j.wear.2023.204743

[2] N.S. Nandakumar, K.S.K. Sasikumar, M. Sambathkumar and N. Saravanan, “Investigations on AWJ Cutting Process of Hybrid Aluminium 7075 Metal Matrix Composites Using Nozzle Oscillation Technique,” Materials Today: Proceedings 33, (2020): 2798–2802. https://doi.org/10.1016/j.matpr.2020.02.686

[3] J. Liang, H. Qiao, J. Zhao, Z. Cao, S. Wang and Y. Zhang, “Study on Water Jet Stability and Processing Morphology of Groove Cutting Using Water Jet Guided Laser,” Optics and Laser Technology 174, (2024): 110670. https://doi.org/10.1016/j.optlastec.2024.110670.

[4] C. Chaturvedi, P. Sudhakar Rao and M.Y. Khan, “Optimization of Process Variable in Abrasive Water Jet Machining (AWJM) of Ti-6Al-4V Alloy Using Taguchi Methodology,” Material Today: Proceeding 15, (2021): 6120-6127. https://doi.org/10.1016/j.matpr.2021.05.040

[5] S. Wang, D. Hu, F. Yang and P. Lin, “Investigation on Kerf Taper in Abrasive Waterjet Machining of Aluminium Alloy 6061-T6,” Journal of Materials Research and Technology 15, (2021): 427 – 433. https://doi.org/10.1016/j.jmrt.2021.08.012

[6] R. Pahuja, M. Ramulu and M. Hashish, “Surface Quality and Kerf Width Prediction in Abrasive Water Jet Machining of Metal-Composite Stacks,” Composites Part B, (2019): 175. https://doi.org/10.1016/j.compositesb.2019.107134.

[7] P. Karmiris-Obratański, N.P. Karkalos, R. Kudelski, E.L. Papazoglou, and A.P. Markoloulos, “On The Effect of Multiple Passes on Kerf Characteristics and Efficiency of Abrasive Waterjet Cutting,” Metals 11, (2021): 1–14. https://doi.org/10.3390/met11010074

[8] Y. Natarajan, P.M, Murugesan, M. Mohan and S.A.L.A. Khan, “Abrasive Water Jet Machining Process: A State of Art of Review,” Journal of Manufacturing Processes 49, (2020): 271–3. https://doi.org/10.1016/j.jmapro.2019.11.030

[9] D.K. Shanmugam, J. Wang and H. Liu, “Minimisation of Kerf Tapers in Abrasive Waterjet Machining of Alumina Ceramics Using A Compensation Technique,” International Journal of Machine Tools and Manufacture 48 (14), (2008): 1527–1534. https://doi.org/10.1016/j.ijmachtools.2008.07.001

[10] S. Saravanan, V. Vijayan, S.T. Jaya Suthahar, A.V. Balan, S. Sankar and M. Ravichandran, “A Review on Recent Progresses in Machining Methods Based on Abrasive Water Jet Machining,” Materials Today: Proceedings 21 (1), (2020): 116–122. https://doi.org/10.1016/j.matpr.2019.05.373

[11] P. Karmiris-Obrata´nski, N.E. Karkalos, P. Kudelski, E.L. Papazoglou and A.P. Markopoulos, “On The Effect of Multiple Passes on Kerf Characteristics and Efficiency of Abrasive Waterjet Cutting,” Metals 11, (2021): 74. https://doi.org/10.3390/met11010074

[12] H. Liu, J. Wang, N. Nelson and R.J. Brown, “A Study of Abrasive Waterjet Characteristics By CFD Simulation,” Journal of Materials Processing Technology 153–154 (1–3), (2004): 488–493. https://doi.org/10.1016/j.jmatprotec.2004.04.037

[13] M.C.P. Selvan, N.M.S. Raju and H.K Sachidananda, “Effects of Process Parameters on Surface Roughness in Abrasive Waterjet Cutting of Aluminium,” Frontiers of Mechanical Engineering 7 (4), (2012): 439–444. https://doi.org/10.1007/s11465-012-0337-0

[14] Y. Qian, L. Wan, X. Wang, G. Zhang and D. Li, “The Cylindrical Surface Characteristics of AA7075 Aluminium Alloy Machined by Abrasive Waterjet with Circular Cuts,” Journal of Materials Research and Technology 26, (2023): 4975–4988. https://doi.org/10.1016/j.jmrt.2023.08.261

[15] J. Xie, Y. Qiao, Z. Wang, Y. Qi, Q. Xu, K. Shemtov-Yona, P. Chen and D. Rittel, "Application of The Taguchi Method to Areal Roughness-Based Surface Topography Control by Waterjet Treatments," Applied Surface Science Advances 19, (2024): 100548. https://doi.org/10.1016/j.apsadv.2023.100548

[16] A.M. Adem and H.E. Azmeraw, "The Manufacturing Practices and Parameters Optimization on Abrasive Jet Machining for Surface Preparation of Mild Steels," Results in Engineering 15, (2022): 100457. https://doi.org/10.1016/j.rineng.2022.100457

[17] Andrzej Perec, "Optimization of Abrasive Water Jet (AWJ) Cutting Process Accuracy," Procedia Computer Science 225, (2023): 1045–1052. https://doi.org/10.1016/j.procs.2023.10.092

[18] C. Joel and T. Jeyapoovan, "Optimization of Machinability Parameters in Abrasive Water Jet Machining of AA7075 Using Grey-Taguchi Method," Materials Today: Proceedings 37, (2021): 737–741. https://doi.org/10.1016/j.matpr.2020.05.741

[19] K. Gowthama, H.M. Somashekar, B. Suresha, S. Rajole and N. Ravindran, "Optimization of Abrasive Water Jet Machining Process Parameters of Al 7071 Using Design of Experiments," Materials Today: Proceedings 52, (2022): 2102–2108. https://doi.org/10.1016/j.matpr.2021.12.380

[20] A. Deaconescu and T. Deaconescu, "Response Surface Methods Used for Optimization of Abrasive Waterjet Machining of The Stainless Steel X2 Crnimo 17-12-2," Materials 14, (2021): 2475. https://doi.org/10.3390/ma14102475

[21] N.P. Singh, D.S. Srinivasu and N.R. Babu, "A Study on The Interaction of Jet with Constituent Layers of Multilayered Structure in Through Kerfing with Abrasive Waterjets," Journal of Manufacturing Processes 60, (2020): 117–133. https://doi.org/10.1016/j.jmapro.2020.10.046

[22] A.S.E. Mesalamy and A. Youssef, "Enhancement of Cutting Quality of Abrasive Waterjet by Using Multipass Cutting Strategy," Journal of Manufacturing Processes 60, (2020): 530–543. https://doi.org/10.1016/j.jmapro.2020.10.036

[23] M.C.P. Selvan, N.M.S. Raju and H.K. Sachidananda, "Effects of Process Parameters on Surface Roughness in Abrasive Waterjet Cutting of Aluminium," Frontiers of Mechanical Engineering 7(4), (2012): 439–444. https://doi.org/10.1007/s11465-012-0337-0

[24] M. Płodzie´n, L. Zyłka, K. Zak and S. Wojciechowski, "Modelling The Kerf Angle, Roughness and Waviness of The Surface of Inconel 718 in an Abrasive Water Jet Cutting Process," Materials 16, (2023): 5288. https://doi.org/10.3390/ma16155288

[25] J.M. Llanto, M. Tolouei-Rad, A. Vafadar and M. Aamir, "Recent Progress Trend on Abrasive Waterjet Cutting of Metallic Materials: A Review," Applied Sciences 11, (2021): 11083344. https://doi.org/10.3390/app11083344

[26] A.A. Kuttan, R. Rajesh and M.D. Anand, "Abrasive Water Jet Machining Techniques and Parameters: A State of the Art, Open Issue Challenges and Research Directions," Journal of the Brazilian Society of Mechanical Sciences and Engineering 43, (2021): 220. https://doi.org/10.1007/s40430-021-02898-6

[27] R. Melentiev and F. Fang, "Recent Advances and Challenges of Abrasive Jet Machining," CIRP Journal of Manufacturing Science and Technology 22, (2018): 1–20. https://doi.org/10.1016/j.cirpj.2018.06.001

[28] J.J.R. Jegaraj and N.R. Babu, "A Strategy for Efficient and Quality Cutting of Materials with Abrasive Waterjets Considering the Variation in Orifice and Focusing Nozzle Diameter," International Journal of Machine Tools and Manufacture 45, (2005): 1443–1450. https://doi.org/10.1016/j.ijmachtools.2005.01.020

[29] W.N.F. Mohamad, M.S. Kasim, M.Y. Norazlina, M.S.A. Hafiz, M.S.A., R. Izamshah and S.B. Mohamed, "Effect of Standoff Distance on The Kerf Characteristic During Abrasive Water Jet Machining," Results in Engineering 6, (2020): 100101. https://doi.org/10.1016/j.rineng.2020.100101

[30] M. Li, M. Huang, Y. Chen, P. Gong and X. Yang, "Effects of Processing Parameters on Kerf Characteristics and Surface Integrity Following Abrasive Waterjet Slotting of Ti6Al4V/CFRP Stacks." Journal of Manufacturing Processes 42, (2019): 82–95. https://doi.org/10.1016/j.jmapro.2019.04.024