2017 WJTA-IMCA Conference and Expo
October 25-27, 2017 ● New Orleans, Louisiana

Paper

AN ANALYSIS OF THE ABRASİVE WATER JET MACHINING OF POLYETHYLENE USING L9 ORTHOGONAL ARRAY

F. Kartal
The University of Kastamonu,
Kastamonu, Turkey

ABSTRACT

In this study, Taguchi method was applied to find optimal process parameters for cutting 100 mm thick (HDPE) polyethylene sheet material with AWJ. This experimental study examines the effect of the process parameters on the material removal rate and average surface roughness values of polyethylene workpieces. For the optimizing the cutting process parameters with AWJ is to optimize the cutting efficiency and the standoff distance, the abrasive flow rate and traverse speed with the Taguchi method. Also used the ANOVA and signal-to-noise ratio (SN Ratio) to determine the optimal parameters. The L9 orthogonal array was used for parameters and response results were assigned. For each combination, a single experiment was performed and optimal results were obtained for the AWJ cutting with SN ratio. It has been verified that the specified optimal AWJ cutting process parameters meet the actual needs for processing of polyethylene in practice.

Keywords: Abrasive Water Jet Machining (AWJM), Taguchi Method, ANOVA, S/N Ratio, MRR

1. INTRODUCTION

The abrasive water jet (AWJ) machining method is a non-conventional machining process which has gained widespread use in the recent years [1-3]. A high-pressure water jet and the abrasive material are used for machining as part of this technology [1-3]. Due to a number of advantages this technology offers, it has gained widespread use in the industry [4-6]. There are two types of water jets: the abrasive jet and pure waterjet. In the process of pure waterjet cutting, only pressurized water is used in order to cut work pieces [5-8]. Such a cutting method is commonly used in order to cut soft material such as cardboards, leather, textiles, fiber plastics, food or thin aluminum sheets [1-5]. In the process of the abrasive jet machining, on the other hand, the abrasive particles are accelerated with the water flow and then applied to the work piece passing through a nozzle (or focusing tube) [8,9]. AWJ cutting is commonly used to machine materials such as stainless steel, glass, ceramics, titanium alloys, composites, etc. AWJ system commonly consists of four main parts. These are water hopper, pressure generator, jet generator and the abrasive feed systems [1-10].

Polyethylene is a material commonly used in the modern times. The use of plastics with superior properties has become widespread in many fields, including precision tools, electronics and optics. Due to the requirement of higher dimensional precision and a better surface machining, plastic materials used in these fields necessitate the use of machining processes instead of casting processes [10, 11].

The main purpose of this study is to analyze the effects of machining parameters on the surface roughness and the material removal rate of Polyethylene material using AWJ cutting methods. A limited number of authors have analyzed Polyethylene plastic material in combination with the abrasive waterjet machining. Therefore, the Taguchi experimental design was used in this study.

2. EXPERIMENTAL STUDY

2.1. Material

Polyethylene (PE) is a widely used plastic material offering a wide range of areas of use in film packaging and insulated electrical container and piping systems with its customizable properties depending on its molecular compatibility [10,11]. A high density polyethylene (HDPE) work piece (see Fig. 1) with the properties as listed in Table 1 was used in this study.

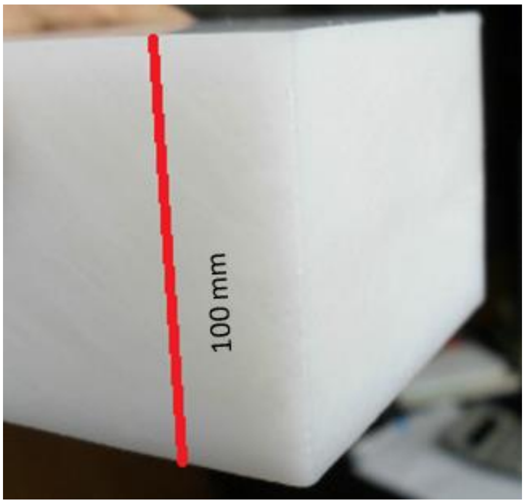

Figure 1. HDPE polyethylene 100 mm thick sheet.

Table 1. Mechanical properties of Polyethylene.

Material	**Density (kg/m^3)**	**Tensile strength (MPa)**	**Elongation at Yield (%)**	**Hardness, Shore D**
LDPE	920	24	10	59

2.2. Designs of Experiments

An experimental design which uses a Taguchi L9 orthogonal array was preferred for the cutting parameters analyzed in this study. This experimental design involves three control parameters and three levels as shown in Table 2. The best results to be obtained for the study were defined as the minimal SR value and the maximal material removal rate. The experiment was run for each value defined in three replications. The optimization of observed values was performed using standard ANOVA comparisons and in accordance with the Taguchi method.

Table 2. AWJ proses control parameters and their levels

Factor	Column	Level 1	Level 2	Level 3
Traverse Speed (mm/min)	A	70	110	150
Abrasive Flow Rate (g/min)	B	100	200	300
Stand of Distance (nun)	C	2	5	8

2.3. Constant parameters

All the material removal procedures involved a single pass cutting. Feed pressure, nozzle traverse speed and the standoff distance were controlled using the operator control panel. Surface roughness, an output parameter used in defining the surface quality, was calculated in terms of the arithmetic mean of roughness (Ra). Taylor-Hobson (Surtronic 3+) surface roughness measuring device was used for this part of the study. Surface roughness were measured at the center of the cut for each sample. Each Ra measurement replicated for 3 times and the arithmetic mean of these three values was used in order to minimize the deviation. The other cutting parameters were constant and the parts of the lathe were replaced by new parts frequently in order to minimize the effects of wear. Table 3 shows the relevant information for these constant parameters. As shown in Table 2, this study involves three control parameters and three levels and Table 4 shows the experimental design and results obtained. Observed according to Taguchi method, the values are calculated using ‘larger the better’ approach for material removal rate and ‘smaller the better’ approach for surface roughness. The pressure was held constant at 350MPa. Thus, the observed maximum and minimum values for MRR and SR were defined. Then, the experiment was replicated three times for each parameter. The optimization of observed values was performed using ANOVA and S/N ratio comparisons with regards to the Taguchi method.

Table 3. Constant parameters and their values

Parameters	Orifice diameter	Focusing tube diameter	Water jet pressure	Abrasive type	Abrasive size
Value	0.20 mm	0.762 nun	350 MPa	Garnet	80 mesh

Table 4. L9 orthogonal array experimental order and results

Exp. No	Traverse speed (mm/min)	abrasive flow rate (g/min)	standoff distance (mm)	MRR (mm3/min)	Ra (µm)
1	70	100	2	30	5
2	70	200	5	31	4,5
3	70	300	8	31,2	4,7
4	110	100	5	29	5,8
5	110	200	8	30	6
6	110	300	2	31,3	5,5
7	150	100	8	28	8
8	150	200	2	25	7,5
9	150	300	5	27	7,2

3. RESULTS AND DISCUSSIONS

The main effects plot for machining parameters on the surface roughness is shown in Fig. 2. This diagram shows the effect of each factor for all three levels. The lowest Ra value was obtained statistically from the experimental design involving nozzle traverse speed of 1, level 70mm/min, the abrasive flow rate of 3 and the standoff distance of 5mm in the experimental conditions defined in the polyethylene material of 100mm thickness. Thus, the optimal parameter selection for the surface roughness was found to be A1, B3, and C2. According to the ANOVA performed, it was found that all the parameters explored had statistically insignificant effects, however, these parameters directly affected the numerical and visual outcome.

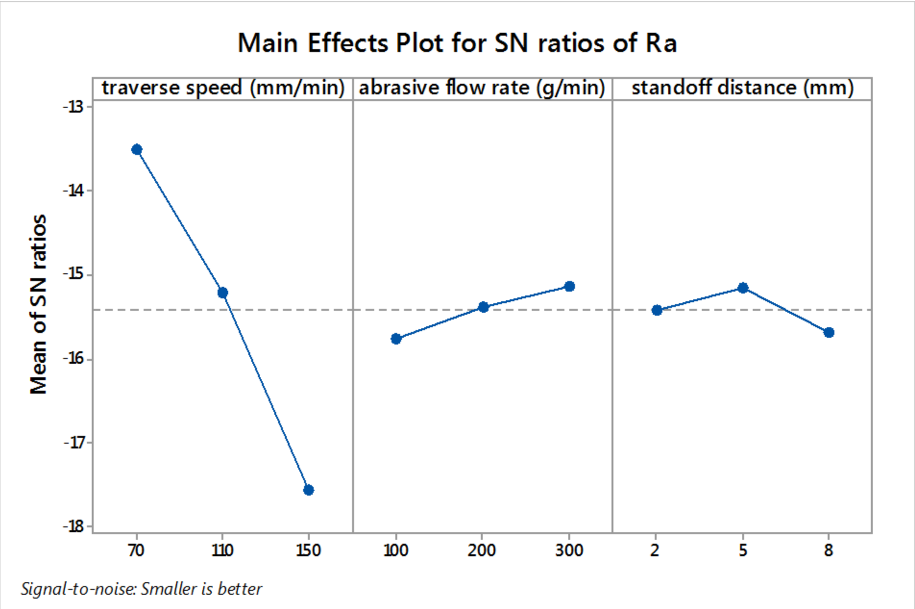

Figure 2. Main effect plots for Ra

The main effects plot for machining parameters on the material removal rate is shown in Fig. 3. The highest MRR value was obtained statistically from the experimental design involving nozzle traverse speed of 1, level 70mm/min, the abrasive flow rate of 3 and the standoff distance of 8 mm. Thus, the optimal parameter selection for the surface roughness was found to be A1, B3, and C3; however, as the standoff distance of 8mm has an adverse impact on the surface roughness, the standoff distance of 5mm is believed to be a better option. Nevertheless, according to the ANOVA performed, it was found that all the parameters explored had statistically insignificant effects, however, these parameters directly affected the numerical and visual outcome.

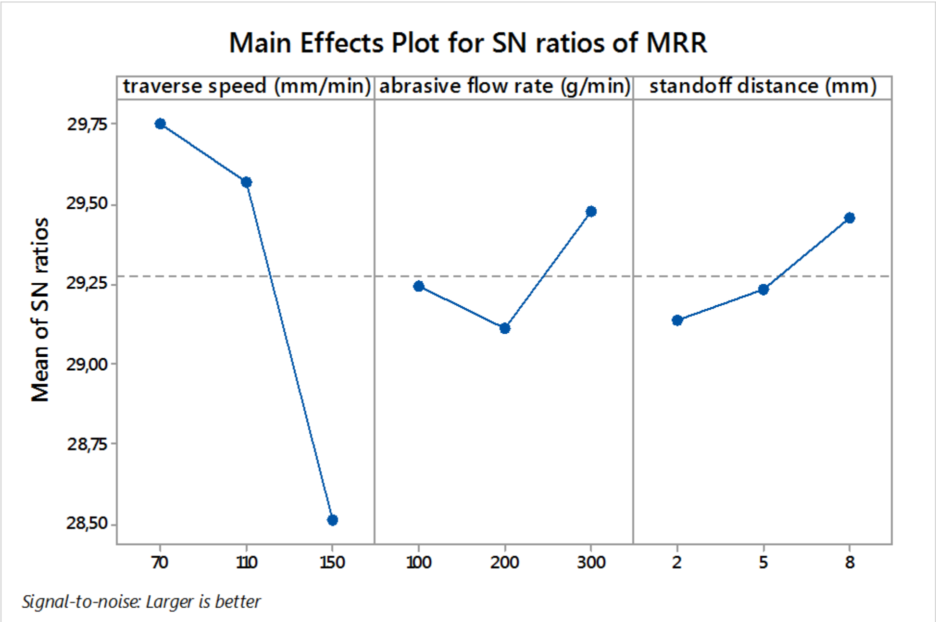

Figure 3. Main effect plot for MRR.

Fig. 4 shows the surface images of the workpiece of 100mm thickness machined using nozzle traverse speeds of 70, 110, and 150mm/min. It is possible to observe in Fig. 4 the deformation of the surface when the nozzle traverse speed is increased by 100%.

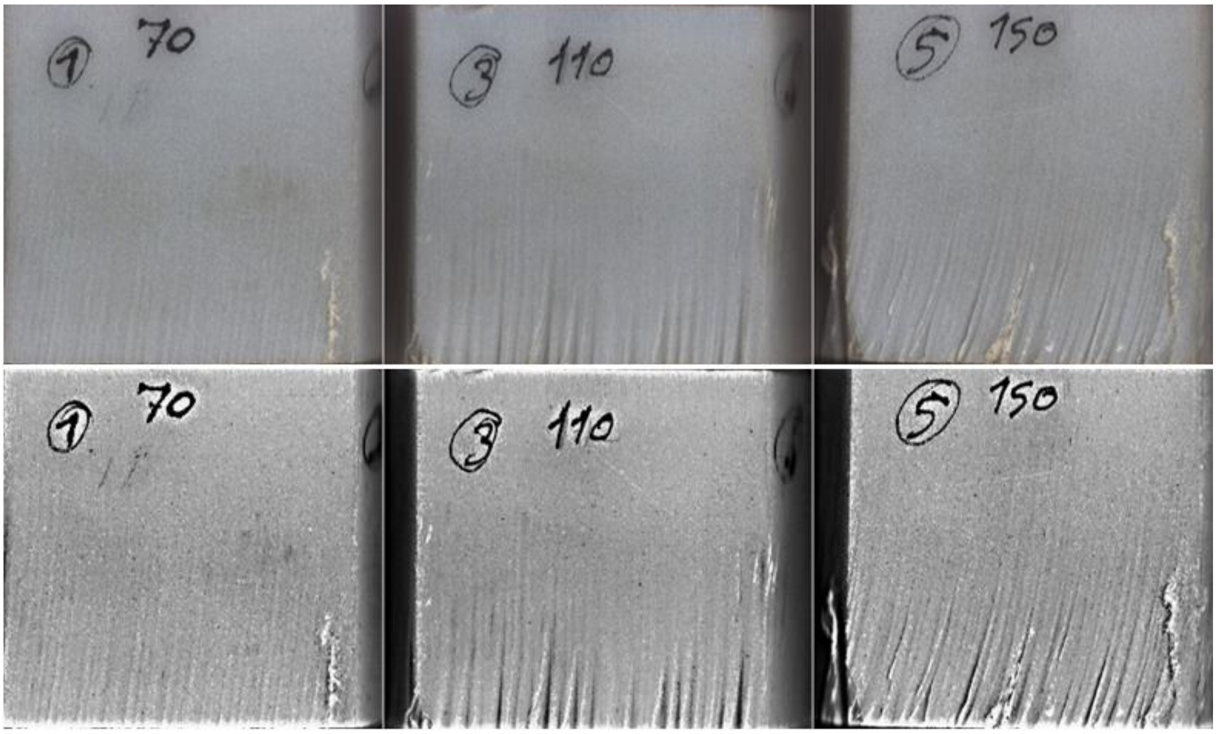

Figure 4 Specimens after Machining for polyethylene

3.1. CONFIRMATION TEST

Confirmation tests were conducted using the optimal combinations obtained for the process parameters in Taguchi analysis. These confirmation tests were used to estimate and confirm the improvement in quality for machining of polyethylene material. The estimated process combination was found to be A1B3C2 for SR, while it was A1B3C3 for MRR, however, it is recommended to use C2 instead as the use of C3 will increase the surface roughness. The MRR value was found to be 31.40 mm3/min and SR value was found to be 4.7 µm when the surface roughness is not the primary concern and the workpiece is merely required to be cut.

4. CONCLUSIONS

This study reports an analysis of the machining parameters used in the machining of polyethylene material using the abrasive waterjet in term of their effects on the surface roughness and material removal rate. According to the results obtained, the following conclusions can be drawn for the efficient machining of polyethylene material using the abrasive waterjet:

- Nozzle traverse speed is found to be the most significant factor for MRR and SR during the abrasive waterjet cutting. Experimental results show that nozzle traverse speed has a governing effect on the roughness criteria.
- The optimal stand-off distance was found to be 5mm fır surface roughness and 8mm for material removal rate; however, it can be taken 5mm also for material removal rate depending on the surface roughness requirements for the output.
- Lower the abrasive feed rate or increased stand-off distance lead to deformation of the surface of polyethylene material being machined. This deformation may involve helical dents on the surface.
- The optimal parameter combination for minimum surface roughness and maximum material removal rate is recommended to be at A (70), B (300) and D (5).
- It is also recommended to use increased amounts of the abrasive particles in order to reduce the surface roughness.

Acknowledgements

The author wishes to thank CT CUTTING TECHNOLOGIES in Istanbul, TURKEY for their assistance in the experimental work.

REFERENCES

1. Momber, A., Kovacevic, R. "Principles of Abrasive Waterjet Machining". Springer-Verlag, London, 1998.
2. Hashish M. "A model for abrasive waterjet (AWJ) machining". Transactions of ASME Journal of Engineering Materials and Technology, vol. III: pp 154-162, 1989.
3. Farhad Kolahan, Hamid Khajavi A. "A statistical approach for predicting and optimizing depth of cut in AWJ machining for 6063-T6 Al alloy". World Academy of

Science, Engineering and Technology 59, 2009.
4. M.Sreenivasa Rao, S.Ravinder, A. Seshu Kumar-Parametric Optimization of Abrasive Water jet Machining for Mild Steel using Taguchi Approach, International Journal of Current Engineering and Technology, feb-2014, ISSN 2277-4106.
5. Jun Wang- A machinability study of polymer matrix composites using abrasive water jet cutting technology; Journal of Materials Processing Technology (1998) 30–35.
6. V.K. Krishnan, CO2 laser cutting of polymer matrix composites, M. Eng. Sc. Thesis, Queensland University of Technology, 1996.
7. N.S. Guo, G. Louis, G. Meier, Surface structure and kerf geometry in abrasive waterjet cutting: formation and optimization, 7th American Waterjet Conf., Seattle, Washington, USA (1993).
8. W. Koenig, Machining of fibre reinforced plastics, Ann. CIRP 34 (2) (1985) 537–548.
9. Wang, J. (1999). Abrasive waterjet machining of polymer matrix composites–cutting performance, erosive process and predictive models. The International Journal of Advanced Manufacturing Technology, 15(10), 757-768.
10. Kaddeche, M., Chaoui, K., & Yallese, M. A. (2012). Cutting parameters effects on the machining of two high density polyethylene pipes resins: Cutting parameters effects on HDPE machining. Mechanics & Industry, 13(5), 307-316.
11. M. Alauddin, Plastics and their machining: A review, J. Mater. Proc. Technol. 54 (1995) 40–46