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

Paper

THE KERF ANALYSIS IN ABRASIVE WATERJET MACHINING OF DUCTILE CAST IRON

F. Kartal
University of Kastamonu,
Kastamonu, Turkey

ABSTRACT

In this study, an experimental research was carried out to reduce or eliminate the kerf taper in the AWJ machining of ductile cast iron section using a kerf-taper compensation technique. Kerf taper is a unique and unwanted geometric formation created due to abrasive water jet processing. In the experiments, ductile cast iron plate of 20mm thickness was used. The parameters; the nozzle feed speed (100, 200 and 300 mm/min), abrasive flow rate (250, 350 and 450 g/min) were explored during abrasive water jet machining. During the experimental study, the pump pressure (380 MPa), nozzle diameter (0.75 mm) and abrasive (Garnet form 80 mesh size) were held constant. Analysis of variance (ANOVA) was used to assess the data obtained in order to determine the important factors affecting the Kerf angle. The results show that the nozzle feed rate is the most significant factor in the formation of kerf.

Keywords: Abrasive waterjet (AWJ), Machining, Kerf taper, Kerf characteristics

1. INTRODUCTION

Abrasive waterjet cutting involves high velocity water flow and abrasive material in order to cut almost any type of workpiece. A water flow with a pressure between 275MPa and 415MPa is sprayed through a sapphire, ruby or diamond waterjet nozzle [1,2]. The water then creates vacuum which allows the abrasive material to be added to the water in a mixing chamber. The flow momentum of the waterjet then accelerates the abrasive particles as it passes through the nozzle [2,3]. Abrasive waterjet (AWJ) cutting offers a number of advantages when compared to other cutting technologies available such as elimination of thermal degradation, ease of machining of several engineering materials and hard-to-machine materials such as aluminium and ceramics, high flexibility and lower cutting forces involved [1-3] Nevertheless, the cutting quality of this technology, especially kerf taper which is characterized by a top kerf wider than the bottom, is one of the obstacles in applications [1-5]. In the last decade, significant research effort was made in order to better understand the kerf taper as part of the AWJ cutting and to minimize it [4,5]. Cast iron is a material which offers the properties of steel and other cast iron materials and is being used in many industries today with ever-improving material properties.

Kerf width is a unique and unwanted geometric formation, a side product of abrasive waterjet machining. This study involves an experimental design aimed at minimizing the kef taper formation on the cast iron workpiece during AWJ machining using specific parameters.

2. MATERIALS AND METHODS

2.1. Materials

Cast iron was selected as the experimental material as it has a wide area of usage offering acceptable machinability properties. Chemical content of the material is shown in Table 1. Workpieces of 20mm thickness were used in the experiments.

Table 1. Chemical composition of cast iron

Element	C	Si	Mn	P	S	Mr	Ni	Fe
(%)	3.8	1.9	0.1	0.03	0.004	0.034	0.015	remain

2.2. Experimental conditions

A computer-controlled abrasive waterjet machine with 3D machining capability was used in the study. The cutting experiments were performed by a private company operating in Istanbul (Fig. 1). Conventional experiment design methods are known for their disregard for the interaction between factors involved which may lead to the misinterpretation of the experiment results. Experimenting on all the possible combinations, on the other hand, will lead to higher costs and increased amount of time necessary for the completion of the study even to a point experimental design is impracticable. It would be possible to apply a full-factorial experiment design, however, 27 individual experiments would cost a lot more. Therefore, only a portion of the processes defined in full-factorial experiment was used. There are a number of strategies which allow for ideal method selection. And one of them is Taguchi's method for vertical sectorization deployment which significantly reduces the number of experiments conducted in order to collect necessary data. Kerf is a machining-related term used to define the material removed during cutting. Kerf width, as shown in Fig. 2, is the angle formed due to the difference between the width of the top and bottom part of the cut. Table 4 shows the data obtained from the observations along with the design matrix. Minitab statistical software is the best tool for data-oriented quality improvement studies. MINITAB (v. 17) was used in this study for ANOVA and for the graphs included. Top kerf width, *Wt*, bottom kerf width, *Wb*, workpiece thickness, *t*, and kerf taper angle, *θ*, are given in Fig. 2. Equation 1 shows the formula used to calculate the kerf taper angle.

Figure 1. Water jet process used in the experiment.

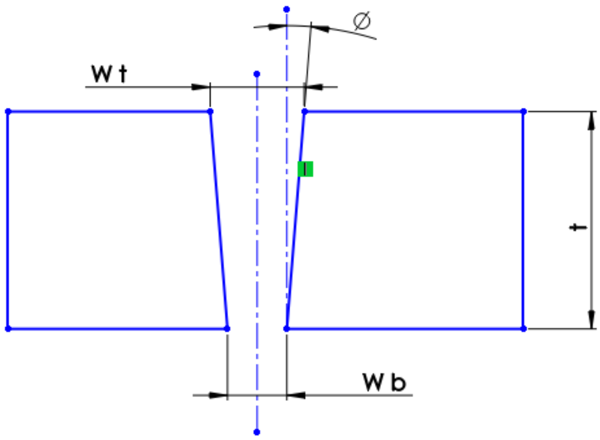

Figure 2. Kerf formation illustration

$$\theta = \frac{\arctan(Wt - Wb)}{2 * t} \qquad (1)$$

Among the three machining parameters involved in abrasive waterjet cutting are nozzle feed rate, abrasive flow rate and water pressure. These three parameters can be altered by the operator using the controls available on the device. The parameters held constant throughout the experiments are shown in Table 3.

Table 2. Experimental factor and level information

Factor	**Unit**	**Values**
Water Pressure	MPa	150; 250; 350
Nozzle feed rate	mm/min	100; 200; 300
Abrasive flow rate	g/min	250; 350; 450

Table 3. Constant parameters.

Abrasive material	Garnet
Orifice diameter	0.13 mm
Nozzle diameter	1.02 mm

Nozzle length	76 mm
Jet impingement angle	90°

3. RESULT AND DISCUSSION

Kerf width that formed after work piece machining is measured using an optical microscope. Main effects plot is a graph of the average reaction of a design parameter or a process variable for each experimental level. This plot is used in order to compare the relative magnitude of the effects of a number of factors. Top kerf width and bottom kerf width were recorded for water pressure, nozzle feed rate and abrasive flow rate and the data was used to create plots as per the Taguchi's experimental methodology. Results obtained were analyzed in accordance with the standard procedure suggested by Taguchi and the criterion of “smaller the better” was used. Analysis of variance (ANOVA) was carried out in order to define the process parameters which have an effect on the top kerf width and bottom kerf width (Tables 4 & 5). Fig 3 shows the effects of process parameters on the top kerf width, while Fig. 4 shows the effects of process parameters on the bottom kerf width. It was observed that top kerf width increases for the 1st and 3rd level of water pressure parameters. Increased water pressure results in a larger waterjet which forms a wider erosion area in the workpiece leading to kerf formation and increased kerf width. It is interesting to note that when the water pressure was set to 2nd level, the effect of water pressure on the top kerf width was decreased. The reason behind such a decrease may be associated with reduced impact of abrasive waterjet at pressure levels higher than the threshold value. The most significant parameter affecting the top kerf width was the nozzle feed rate by 92%. The least significant parameter affecting both the top and bottom kerf widths was water pressure. Both plots show similar patterns in parameter trends. The graphical analysis of the optimal points for the lowest top kerf width showed that water pressure of 250MPa, nozzle feed rate of 100mm/min and abrasive flow rate of 350g/min are optimal values. A similar graphical analysis of the optimal points for the lowest bottom kerf width showed that water pressure of 250MPa, nozzle feed rate of 100mm/min and abrasive flow rate of 350g/min are optimal values.

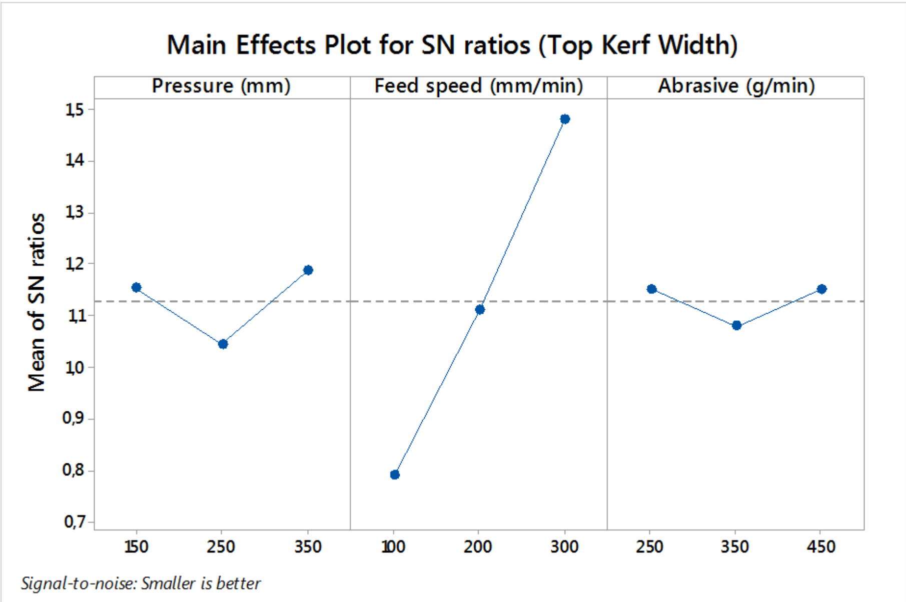

Figure 3. Main effects plot for top kerf width.

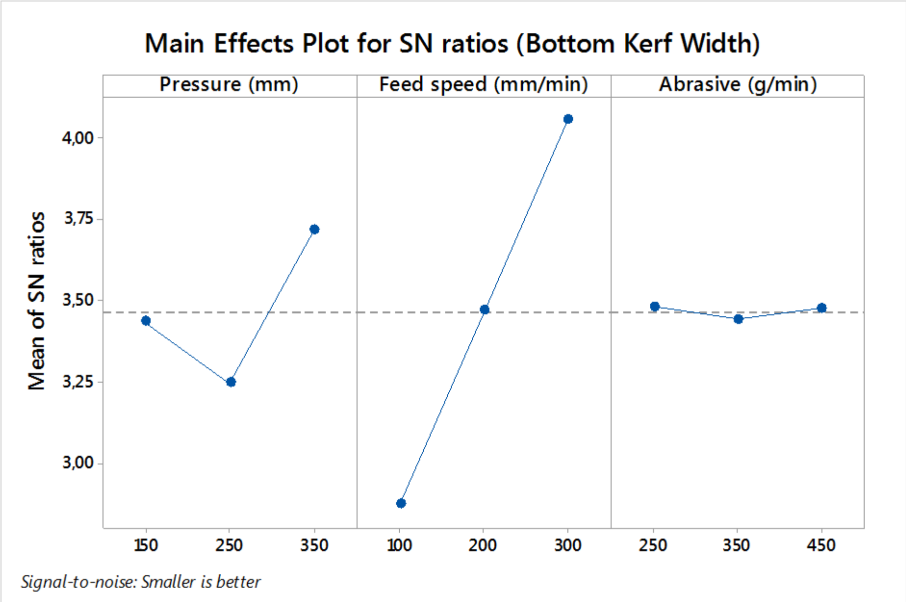

Figure 4. Main effect plots for bottom kerf width.

Table 4. Analysis of variance of top kerf width

Source	DF	Adj SS	Adj MS	F-Value	Contributions (%)
Pressure (mm)	2	0,00035	0,000175	3,25	4,46
Feed speed (mm/min)	2	0,007287	0,003643	67,75	92,80
Abrasive flow rate(g/min)	2	0,000108	0,000054	1	1,38
Error	2	0,000108	0,000054		1,38
Total	8	0,007852			100,00

Table 5. Analysis of variance of bottom kerf width

Source	DF	Adj SS	Adj MS	F-Value	Contributions (%)
Pressure (mm)	2	0,002044	0,001022	10,86	13,75
Feed speed (mm/min)	2	0,012611	0,006305	67	84,81
Abrasive flow rate (g/min)	2	0,000027	0,000013	0,14	0,18
Error	2	0,000188	0,000094		1,26
Total	8	0,01487			100,00

4. CONCLUSIONS

Cast iron workpiece was cut using abrasive waterjet. The results of the experimental study are summarized, as follows:

- It was observed that abrasive waterjet machining offers remarkable cutting and machining properties especially when it comes to the machining of ductile materials such as cast iron.
- Having explored the effects of cutting parameters on both top and bottom kerf widths, it was found that both feed rate and abrasive flow rate played an important role in the kerf width.
- The results of the study showed that the kerf width formed during cutting process has a very significant impact on the machining quality.

- Selected process parameters are water pressure of 250MPa, abrasive flow rate of 350g/min and nozzle feed rate of 100m/min.
- For top kerf width, nozzle feed rate (by 92%) and water pressure (by 4%), respectively, are the most important parameters.
- The optimal process parameter selection for minimum top kerf width requires water pressure of 250 MPa, nozzle feed rate of 100mm/min and abrasive flow rate of 350g/min.
- Among the selected parameters, only the nozzle feed rate has a statistically significant impact on the kerf angle by 92% contribution.
- Abrasive flow rate was found to be less significant for the kerf angle by 1% contribution.
- Many of the studies focusing on optimization of process parameters aim to improve the quality characteristics of a single parameter such as machining depth, surface roughness, material removal rate, kerf geometry, and nozzle erosion. It is necessary for the research to focus on power consumption, size accuracy and multi-purpose optimization.
- AWJM process, today, is still a fertile field for future research.

ACKNOWLEDGEMENTS

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

REFERENCES

1. Ma, C., and R. T. Deam. "A correlation for predicting the kerf profile from abrasive water jet cutting." Experimental Thermal and Fluid Science 30, no. 4 (2006): 337-343.
2. Hlaváč, Libor M. "Investigation of the abrasive water jet trajectory curvature inside the kerf." Journal of Materials Processing Technology 209, no. 8 (2009): 4154-4161.
3. Azmir, M. A., and A. K. Ahsan. "A study of abrasive water jet machining process on glass/epoxy composite laminate." Journal of Materials Processing Technology 209, no. 20 (2009): 6168-6173.
4. Chen, L., E. Siores, and W. C. K. Wong. "Kerf characteristics in abrasive waterjet cutting of ceramic materials." International Journal of Machine Tools and Manufacture 36, no. 11 (1996): 1201-1206.
5. Ochi, Yasuo, Kiyotaka Masaki, Takashi Matsumura, and Takeshi Sekino. "Effect of shot-peening treatment on high cycle fatigue property of ductile cast iron." International Journal of Fatigue 23, no. 5 (2001): 441-448.
6. Chuzhoy, L., R. E. DeVor, S. G. Kapoor, and D. J. Bammann. "Microstructure-level modeling of ductile iron machining." Journal of manufacturing science and engineering 124, no. 2 (2002): 162-169.
7. Zeng, J., & Kim, T. J. (1992). Development of an abrasive waterjet kerf cutting model for brittle materials. In Jet Cutting Technology (pp. 483-501). Springer Netherlands.
8. Shanmugam, D. K., and S. H. Masood. "An investigation on kerf characteristics in abrasive waterjet cutting of layered composites." Journal of materials processing technology 209, no. 8 (2009): 3887-3893.
9. Vikram, G., and N. Ramesh Babu. "Modelling and analysis of abrasive water jet cut surface topography." International Journal of Machine Tools and Manufacture 42, no. 12 (2002): 1345-1354.