Influence of Nozzle Jet Flushing on Wire Deflection and Breakage in Wire EDM

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Abstract. In wire EDM, better exclusion of debris generated in the working gap is very important in order to achieve stable machining performance. When a lot of debris stagnates in the gap, the discharges easily concentrate on the same location, which causes unstable machining performances including frequent wire breakage, low machining rate and low shape accuracy. The debris exclusion from the gap has been conventionally done by jet flushing with upper and lower nozzles. However, the effects of jet flushing on the debris exclusion in the wire EDMed kerf and wire behavior have not yet been clarified sufficiently.

In this study, the flow fields and the distributions of pressure applied on the wire surface due to jet flushing were analyzed by computational fluid dynamics (CFD) analysis, and the deflection of wire was calculated by a structural analysis using the distributions of the forces obtained by the CFD analysis. Furthermore, the effects of machined kerf length on the wire deflection and wire breakage were discussed. As a result, when the machined kerf length is as short as a few mm, the fluid flow in the kerf is significantly disturbed by nozzle jet flushing, which causes unstable large wire vibration. Then, wire breakage frequently occurs. Therefore, it is essential to select the optimum jet flushing conditions in order to prevent wire breakage when the machined kerf length is short.

Introduction

The demand for fine precision machining has recently increased along with the miniaturization of mechanical and electronic products. Therefore, the machine control technology, the optimization of machining conditions and the development of finer wire electrodes have been enhanced for a wire EDM technology. In order to obtain stable machining performance, better exclusion of debris from the machined kerf is also important, since the area of spark generation is very narrow. When a lot of debris stagnates in the machined kerf, secondary discharges possibly occur and these discharges easily concentrate on the same location, which leads to unstable machining performance, wire breakage, low machining rate, large machined surface roughness and low shape accuracy [1,2].

Conventionally, the debris exclusion has been done by jet flushing of working fluid from upper and lower nozzles. The purposes are not only to flush the debris away from the gap, but also to introduce fresh working fluid for dielectric recovery of the gap. However, the effect of jet flushing on the debris exclusion in the kerf and the wire behavior had not yet been examined sufficiently, since such unsteady flow field is not easy to clarify and a precise in-process observation of debris movements in the narrow kerf is very difficult in wire EDM.

Our previous papers [3,4] showed that the flow fields and the debris movements in the kerf could be precisely analyzed by using CFD. As a result, it was clarified that jet flushing with a very high flow rate was effective to some extent, but such a high flow rate would lead to larger wire vibration and lower shape accuracy. However, the hydrodynamic force acting on the wire due to working fluid flow and the effect of jet flushing on the wire behavior are still unclear.

In this study, the distributions of pressure and shear stress applied on the wire electrode surface due to jet flushing were analyzed by the CFD analysis, and the deflection of wire electrode was calculated by a structural analysis using the distributions of the hydrodynamic forces obtained by the CFD analysis. The wire breakage frequently happens when the machined kerf length is short in the practical wire EDM process. In order to clarify such phenomenon, the flow fields in the machined kerf and the wire deflections with different machined kerf length were caluculated. Then, the probability distribution of wire breakage with the machined kerf length was experimentally investigated, and effect of machined kerf length on wire breakage frequency was discussed.

CFD Analysis Model and Conditions

In the field of fluid dynamics, it is possible to solve some difficult-to-solve problems with the help of CFD. The CFD simulations in this study are performed with a commercial software package (CD-adapco STAR-CCM+). This software was operated by solving the governing differential equations of the flow physics by numerical means on a computational mesh. The governing equations are Navier-Stokes equations [5].

Figure 1 shows the CFD model for working fluid area to be analyzed. This is based on an actual wire EDM for steel workpiece under 1st cut conditions. The simulations of fluid flow were done by a finite volume method as a three dimensional unsteady turbulent flow [5]. The kerf width is 0.25 mm, and the side gap distance is 0.025 mm because the diameter of brass wire is 200 μm. The top and bottom wire guide positions were at vertical ends of the model, and the model includes the inside of the nozzle.

Table 1 shows the model conditions. On the upper and lower boundary surfaces, flow inlet circles of 6 mm in diameter were set for nozzle jet flushing, in which the flow rate was set to 6.0 L/min. A downward velocity of 10 mm/min was given to the circumference surface of wire to realize the actual wire running. No slip condition was applied to the surfaces of workpiece, wire and nozzle, whereas other boundaries were modeled to be an imaginary surface with a slip condition. The cell size adjacent to the wire electrode was very small enough to simulate precisely, and the other part was a little coarse for saving calculation time. The effects of impact force associated with sparks and electrostatic force acting on the wire with open voltage were neglected, since CFD analysis with considering these factors is very difficult under the current CFD techniques. Our previous papers [4,6] showed that the CFD analysis result of flow fields in the kerf were very similar to those obtained by the PIV analysis using high-speed observation and estimated by the SEM observations of machined surface, which indicates the high simulation accuracy of the developed CFD model.

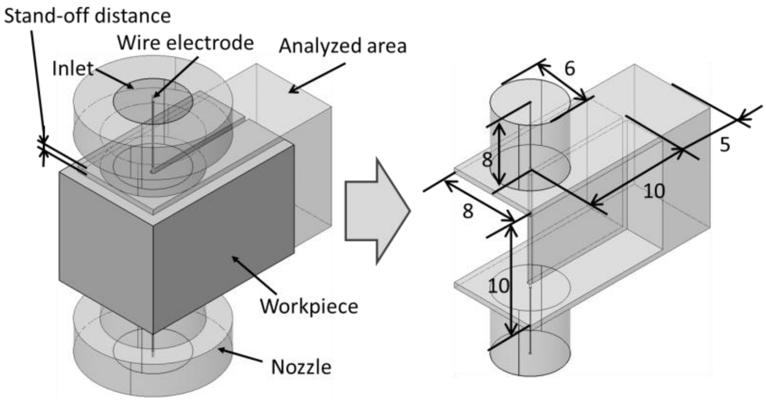

Fig. 1 CFD analysis model

Table 1 CFD model conditions

Workpiece thickness	10.0mm
Machined kerf length L_M	0.5mm-10.0mm
Side gap	0.025mm
Wire diameter	0.2mm
Kerf width	0.25mm
Nozzle diameter	6.0mm
Wire running speed	10.0m/min
Stand-off distance	0.5mm
Flow rate	6.0L/min
Fluid density (Deionized water)	9.976×10^{2}kg/m^{3}
Viscosity (Deionized water)	8.887×10^{-4}Pa・s

Effect of Machined Kerf Length

In practical wire EDM, wire breakage frequently occurs when the machined kerf length is short. In order to clarify this phenomenon, the effect of machined kerf length on flow field of machining fluid and the pressure distribution in the machined kerf were analyzed by CFD simulation.

Figure 2 shows the analyzed results of flow field and pressure distribution. When the machined kerf length is as short as 0.5 mm, the flow from jet flushing nozzle drifted out of the machining kerf without flowing into the kerf. In the case of 1.0 mm kerf length, the flow from the nozzle branches into inside and outside of the machined kerf. When the machined kerf length is 2.0 mm, the flow flowing into the machined kerf a little increases and a vortex generates at the middle part of the workpiece. In this range of the machined kerf length, it was confirmed that the flow field of the working fluid was very unsteady, in which the flow direction in machined kerf significantly changes and the vortex changes its position alternately upward and downward. The pressure distribution in the kerf also changes rapidly. When the machined kerf length is longer than 3.0 mm, most flow from the nozzle flows into the machined kerf and the flow field becomes steady. From these results, it is considered that debris exclusion and wire behavior are very unsteady due to turbulence in the machined kerf when the machined kerf length is shorter than 2.0 mm.

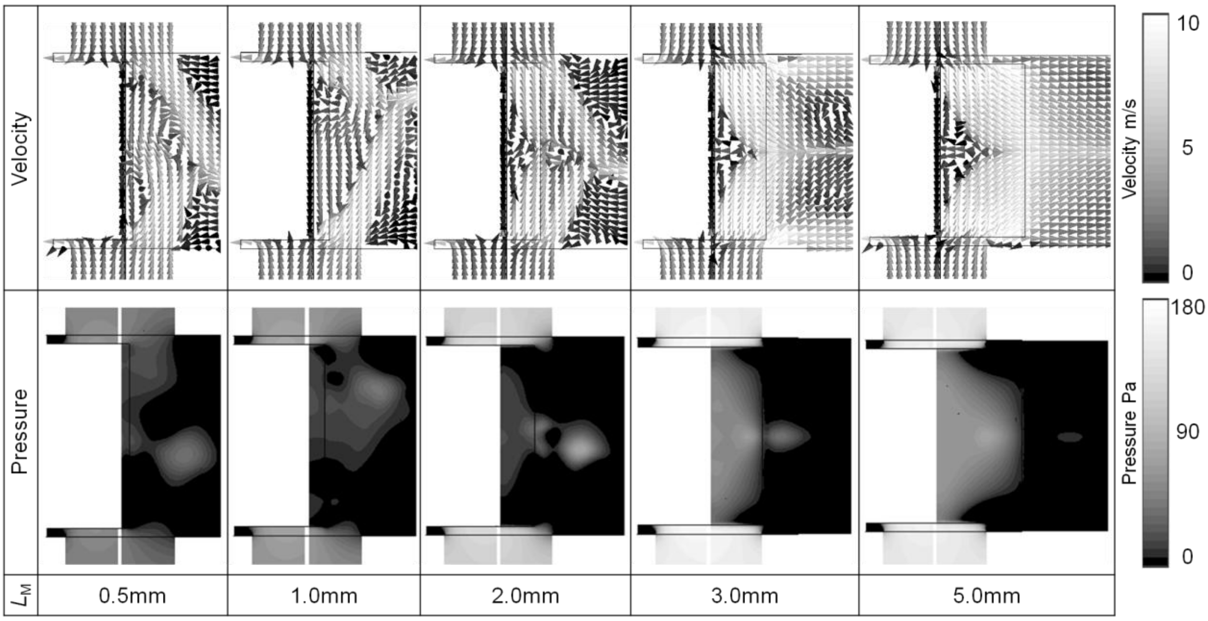

Fig. 2 Flow fields and pressure fields in the machined kerf

Analysis of Hydrodynamic Force Acting on Wire Electrode

There are two types of hydrodynamic force acting on the wire due to the flow by jet flushing, pressure acting perpendicular to the wire surface and shear stress parallel to the surface. Figure 3 shows the distributions of pressure acting on the wire surface with jet flushing analyzed by CFD. Three views are the pressure distributions from the front, side and back of wire for machining direction around the upper workpiece surface. It can be noticed that the pressure on the front surface of wire is higher than that on the back. Consequently, it is thought that the backward force is given to the wire around the upper workpiece surface. In addition, similar pressure distribution could be confirmed around the lower workpiece surface.

Figure 4 shows the distribution of machining direction component of shear stress around the upper workpiece surface, where larger shear stress appears. The flow from nozzle leans particularly around the upper workpiece surface as shown above, which agrees well with the distribution of shear stress. However, the maximum shear stress is only 1kPa, which is much lower than the pressure. Therefore, the pressure distribution has dominant influence on the wire deflection and the influence of shear stress distribution can be neglected.

The analysis results of the pressure distribution showed that the distribution on the wire surface was symmetric in both circumferential and axial directions of wire, except around the upper and lower workpiece surfaces. Therefore, the difference in pressures acting on the front wire surface and the back one was calculated. The results are shown in Figure 5. As shown in the figure, the wire intensively receives the backward force by jet flushing near the upper edge of workpiece. On the other hand, there was little difference in pressure at other parts.

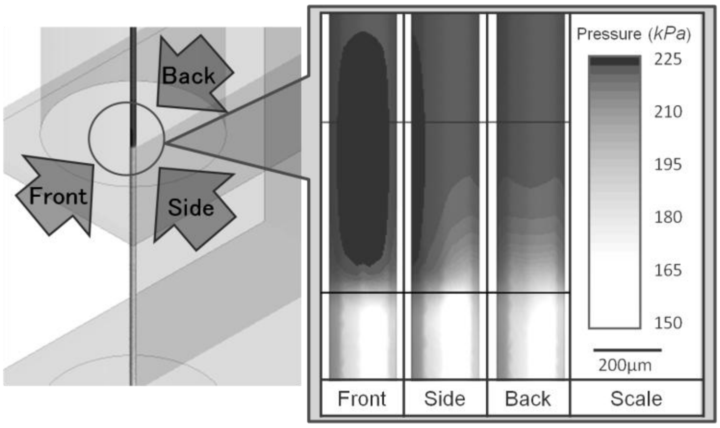

Fig. 3 Pressure distribution on wire surface around upper surface of workpiece

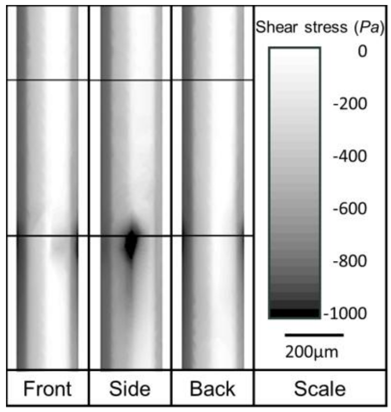

Fig. 4 Shear stress distribution on wire surface

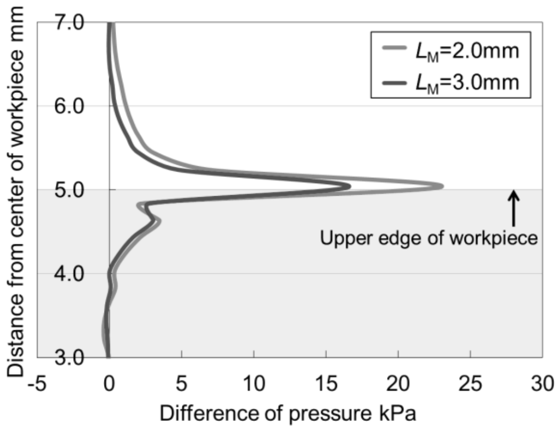

Fig. 5 Difference of pressure acting on the front and back surfaces of wire

Analysis of Wire Deflection

It is supposed that the wire deflect in the opposite direction of machining due to the nozzle jet flushing. In order to estimate the wire deflection due to the jet flushing, the structural analysis of wire deflection due to jet flushing was done using a commercial finite element program (CYBERNET ANSYS Rev. 14.0). The distributions of pressure acting on the wire surface due to jet flushing flow obtained by the CFD analysis were given to the wire surface in the structural analysis model. The wire electrode material is assumed to be a hard brass, and the wire movement is constrained in x-y directions at the upper and lower wire ends. Wire tension is realized by giving a vertical tensile load at the both ends of wire. The analysis conditions are listed in Table 2.

Figure 6 shows the wire deflection in upper half of the analyzed area when the machined kerf length is varied. The machining direction is leftward, and the horizontal scale of the wire displacement is amplified to emphasize the difference in wire deflection. It is understood that the wire electrode is deflected backward under any machined kerf length. Figure 7 shows the variation of maximum wire displacement with machined kerf length. When the machined kerf length is shorter than 3.0 mm, the flow field was not steady, as shown above. Then, the wire maximum displacement value fluctuated with times even when the machined kerf length didn’t change. Therefore, five wire displacements at five different times were calculated in each machined kerf length, and the mean values are plotted with error bar in the graph. When the machined kerf length is shorter than 2.0 mm, the wire displacements and the variations are large because of its turbulence of flow field. When the machined kerf length is 2.0 mm, wire displacement takes maximum value. In this case, the most flow from the jet flushing nozzle goes out from behind the workpiece without flowing into the kerf. Since the cross-sectional area of the outflow, the outflow increases its velocity. For this flow acceleration, it is guessed that the wire displacement at around 2.0 mm machined kerf length becomes larger. When the machined kerf length is longer, the wire displacement decreases gradually with machined kerf length, since the flow field in the kerf becomes stable.

Table 2 Structural analysis conditions

Wire material	Brass
Density	8.4g/cm^3
Young's modulus	106GPa
Poisson ratio	0.35
Diameter of wire	0.2mm
Length between guides	27.0mm
Wire tention	12.0N

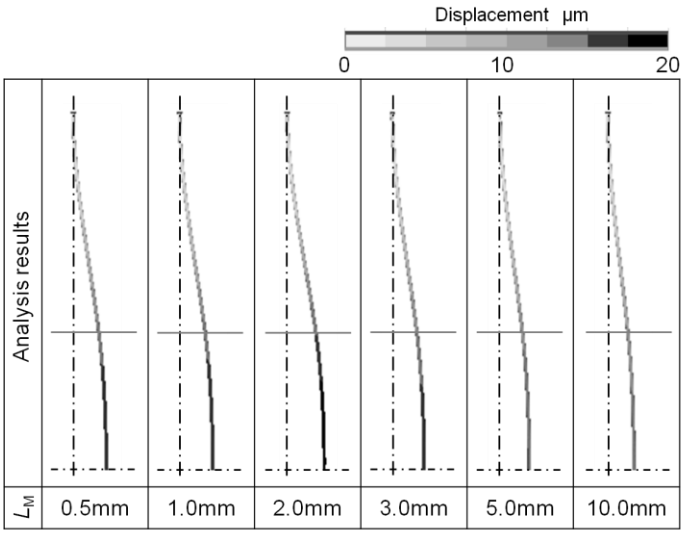

Fig. 6 Difference in wire displacement with machined kerf length

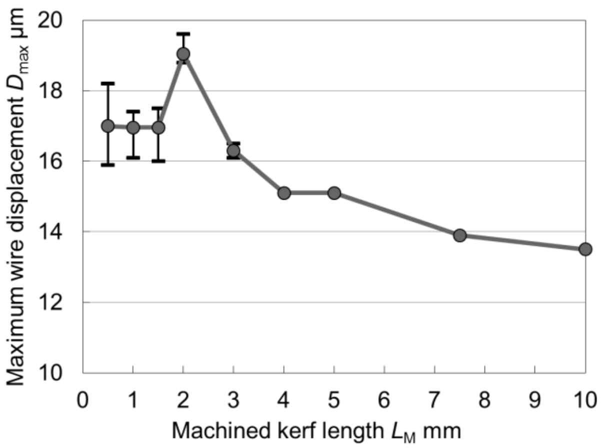

Fig. 7 Variation of maximum wire displacement with machined kerf length

Relation Between Machined Kerf Length and Wire Breakage

In order to clarify the effect of machined kerf length on wire breakage phenomenon, wire breakage frequency with machined kerf length is investigated by the experiments using wire ED machine. Figure 8 shows distribution of wire breakage frequency with machined kerf length when the workpiece thickness is 10.0 mm. In this experiment, duty factor was set to higher value than the machine-maker-recommended one in order to make the wire breakage easier to occur. In the graph, wire displacement with machined kerf length analyzed above is also showed.

As shown in the figure, wire breakage frequently occurs when the machined kerf length is 1.0 to 2.0 mm. In the case of 2.0 mm length or shorter, wire breakage would be caused by the unstable flow field in the machined kerf, large wire deflection and deterioration in debris exclusion. When the machined kerf length is 2.0 to 3.0 mm, the wire breakage frequency decreases, since the flow field becomes stable, and wire deflection and debris stagnation decrease. Therefore, there is a good correlation between the wire breakage frequency and the wire deflection. In other words, the wire breakage frequency becomes larger when the wire deflection is larger.

In wire EDM, the factors affecting the wire deflection were thought to be impact force associated with spark occurrence and electrical static force acting between the wire and the workpiece during the application of open voltage. It is concluded from these result that hydrodynamic force due to jet flushing with nozzle is also one of the dominant factor causing the wire deflection. Therefore, in order to prevent wire breakage, it would be effective to appropriately adjust the jet flushing conditions, such as flow rate, when the machined kerf length is short in early machining stage, in which the flow field of working fluid around the wire in the kerf is unstable.

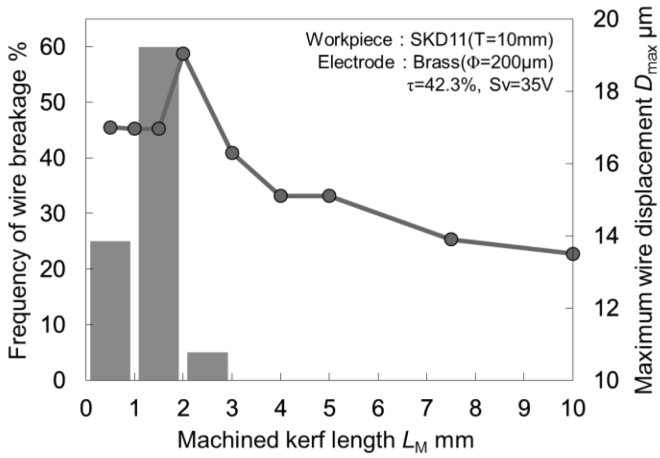

Fig. 8 Distribution of wire breakage frequency with machined kerf length

Summary

In this paper, the effects of machined kerf length on the flow fields in the machined kerf and the wire deflection during wire EDM were numerically analyzed. Also, the effect of machined kerf length on wire breakage frequency was experimentally investigated. The main conclusions obtained are as follows;

(1) In conventional jet flushing method, the hydrodynamic pressure acting on the front surface of wire due to jet flushing from nozzles is larger near the upper and lower edges of workpiece, which intensively gives backward force to wire.

(2) The wire electrode deflects backward and the wire displacement takes a maximum at the midpoint of upper and lower wire guides under any jet flushing conditions by conventional jet flushing method.

(3) A wire breakage tends to often occur at a particular machined kerf length because of very unsteady flow field, and large wire deflection there.

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