New High-Speed Precision Steel Core EDM Wire with New Alloy Coating (SUMISPARK Gamma)

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In recent manufacturing processes for fine parts and semiconductor industries, wire electric discharging machining (EDM) is suitable for the precision machining of cemented carbide molds. Against the backdrop of customer request for processed products with higher quality, electrical discharge machining electrode wire has been expected to exhibit higher performance, such as high-speed machining, high precision, and high strength. Sumitomo (SEI) Steel Wire Corp. has developed discharge machining electrode wire "SUMISPARK Gamma." This electrode wire is coated with the new alloy γ-phase brass on the surface of the steel core. The excellent discharge characteristics and processing condition settings appropriate to the new alloy have achieved high-speed processing and high-accuracy cutting. Furthermore, with one of our core technologies (High-carbon steel wire drawing technologies), we have succeeded in increasing the strength of the steel core. These developments have made it possible to suppress breaking of the electrode wire, increase the wire tension during processing, and suppress the vibration of the wire, thereby allowing precision machining. In this paper, we describe the features and performance of SUMISPARK Gamma.

Keywords: wire electric discharge machining (wire EDM), electrode wire, EDM wire, steel core, γ-phase brass

1. Introduction

Wire electric discharge machining (wire EDM) refers to a machining method in which voltage is applied between a wire that is fed at a constant speed and a workpiece, to produce electrical discharges and achieve local fusion or removal of material from the workpiece by utilizing the heat generated by electric sparks (**Figure 1**). EDM enables high-precision machining that cannot be attained by regular cutting. Three types of EDM electrode wires are used for different purposes depending on the machining precision (wire diameter): inexpensive brass wires for diameters of 0.15 mm or more, expensive tungsten wires for diameters of less than 0.05 mm, and steel core wires (intermediate wires in terms of machining precision and price, with the steel core surface coated mainly with brass).

In recent years, there are growing demands for higher precision, shorter delivery time, and lower cost in the field of precision machining. EDM electrode wires are no exception. Against this backdrop, less expensive electrode wires that can achieve high-speed machining are needed.

Notably, recent wire EDM machines are basically designed to operate automatically by mechanical and electronic control after the initial settings are determined. In most cases, wire EDM machines are operated by a small number of operators or without any operators. Thus, electrode wires require breakage resistance and straightness (which is related to the success rate of automatic wire threading [i.e. automatically pulling a wire through the prepared hole in a workpiece for wire threading]). Electrode wires are required to offer many functionalities at high levels. To meet these requirements, we developed SUMISPARK Gamma, an electrode wire for high-strength steel core wire EDM using unconventional electrode materials. The features and machining performance of this product are discussed below.

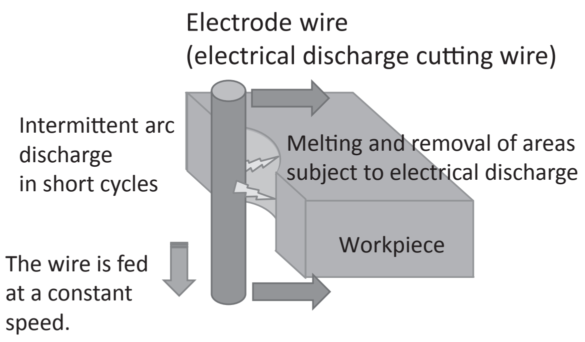


Fig. 1. Schematic diagram of wire EDM

2. Issues of Steel Core EDM Wires

Conventionally, α-phase brass, β-phase brass, or mixed phase brass are used as electrode materials for steel core electrode wires for wire EDM. Wires with a zinc coat on the outermost layer are available for high-speed machining. Zinc has been considered to achieve (i) high-speed machining due to ease of producing electrical discharges (attributed to a low work function) and (ii) stable machining because the evaporation heat of zinc (a low-boiling-point material) offers wire cooling and heat dissipation effects, suppressing concentration of discharge inception points and wire damage and minimizing breakage during machining. However, high-speed machining causes significant damage to workpieces, resulting in low machining precision.

To increase the machining precision, it is necessary to increase the tension and minimize wire oscillation. This increases the risk of breakage. Some customers have increased the machining precision so much that they had to use expensive tungsten wires in order to ensure machining at the tension that conventional steel core electrode wires could not withstand. Increasing the permissible tension limit of electrode wires and thereby enabling machining in the scope achieved by tungsten wires would help reduce the machining cost.

Thus, there are mainly two issues that need to be solved for steel core electrode wires: (i) achieving both high-speed machining and surface precision and (ii) attaining high wire strength.

3. Features of SUMISPARK Gamma

3-1 Features of electrode materials

We found that the machining efficiency can be increased by increasing the amount of zinc (which serves as the discharge inception point in electrode materials) and dispersing the zinc. Notably, we found that γ-phase brass whose zinc content is 60–70% (**Figures 2 and 3**) is superior to other substances in terms of machining speed. Thus, γ-phase brass was employed as the electrode material for SUMISPARK Gamma.

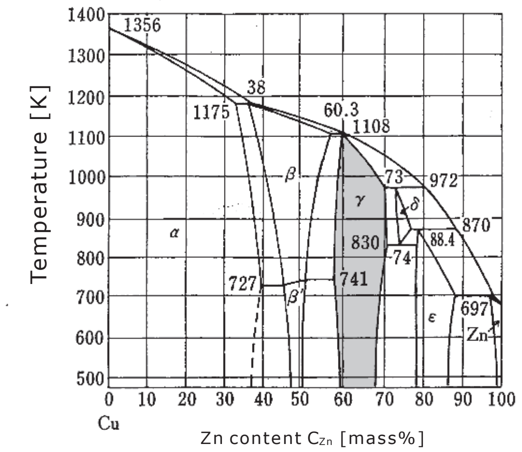
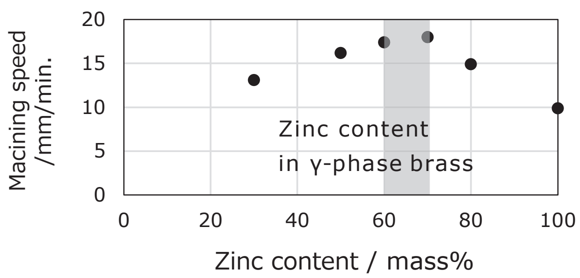


Fig. 2. Copper-zinc binary system diagram[3] Source: Metallic Materials published by Asakura Publishing Co., Ltd.



EDM machine: α-0iEmanufactured by FANUC Corporation
Wire diameter: φ100 μm
Workpiece material: SKD 11 (thickness: 10 mm)
Machining fluid: water

Fig. 3. Wire EDM speed for the zinc content

3-2 Wire structure and characteristics

Figure 4 shows the structural comparison between SUMISPARK Gamma and a conventional steel core electrode wire. SUMISPARK Gamma is a wire in which the steel core surface is thickly plated with γ-phase brass (single phase) (cross section ratio: 16–40%).

The electric conductivity of γ-phase brass is lower than that of α-phase and β-phase brass because the copper ratio in the alloy is low. Thus, the electric conductivity of SUMISPARK Gamma is lower than that of brass-coated steel core electrode wires (**Table 1**).

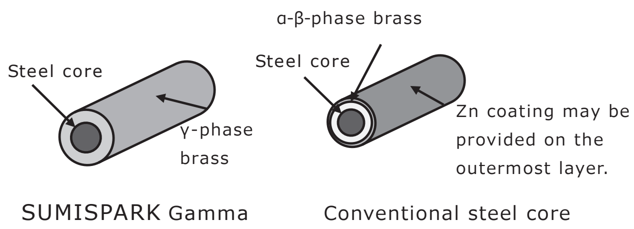


Fig. 4. Schematic diagram showing the structural comparison between SUMISPARK Gamma and a conventional steel core electrode wire

Table 1. Electric conductivity of a steel core electrode wire

	Conventional brass-coated steel core electrode wire	SUMISPARK Gamma
Electric conductivity	14–17%IACS	9–12%IACS

As discussed above, electrode wires are required to feature high strength (tensile strength: 2,000 N/mm^2 or more). The tensile strength required of the steel core is 3,500 N/mm^2 or more. Severe plastic deformation must be performed to increase the wire strength. However, γ-phase brass is a very hard and fragile material with poor workability. Thus, we employed the wire drawing technology of Sumitomo (SEI) Steel Wire Corp. that manufactures small-diameter high-strength brass-coated piano wires such as saw wires and steel cords. Various measures (e.g. use of diamond dies whose surface friction with materials is low among draw dies for wire machining, dispersion of contact pressure between the surface plating and die sliding area by optimizing the die shape and the machining surface reduction rate) were implemented to achieve the manufacture of high-strength steel core electrode wires plated with γ-phase brass. The tensile strength increased to about 1.2 times that of conventional steel core electrode wires (**Figure 5**).

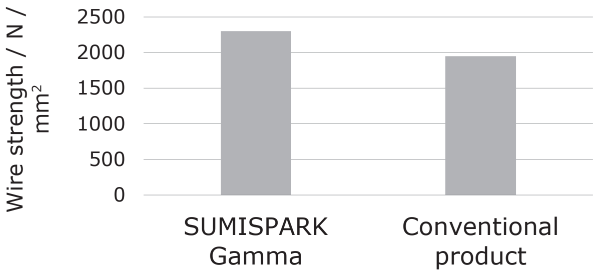


Fig. 5. Strength evaluation results of ø 50 µm products

Wire EDM machines are equipped with an automatic wire threading function as a standard feature. This function automatically pulls through the wire when the wire is temporarily cut due to changes in the machining position or breakage of the wire, etc. In automatic wire threading, the wire is vertically fed from top to bottom, through a prepared hole in a workpiece (about 10 times that of the wire diameter), into the lower nozzle. For this reason, the success rate of automatic wire threading depends largely on the straightness of the electrode wire. Straightness is defined as the range in which a wire of one meter long is most curled when it is vertically suspended, as shown in **Figure 6**.

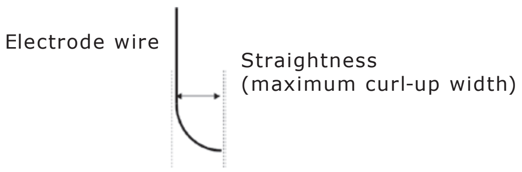


Fig. 6. Schematic diagram of the straightness evaluation technique

By utilizing our proprietary process to ensure straightness, we achieved a straightness of less than 100 mm, which is equivalent to that of conventional steel core electrode wires, while also attaining high strength. This property enables stable operation.

4. EDM Evaluation

We conducted EDM characteristics evaluation tests on a brass-coated steel core electrode wire with a zinc coat (hereafter, "the conventional product") and SUMISPARK Gamma (using ø 50 µm electrode wires). We used carbide alloy G4 (tungsten carbide) (thickness: 10 mm) materials as workpieces. AP-200L manufactured by Sodick Co., Ltd. was used as the EDM machine to perform machining in oil. The machining conditions established by Sodick Co., Ltd. (using a ø 50 µm tungsten wire and a carbide material for cutting [thickness: 10 mm]) were used as the standard settings. **Table 2** shows the main machining conditions. **Figure 9** shows the evaluation results.

Table 2. Machining conditions and standard settings

Machining conditions	ON	OFF	Servo voltage	Machining voltage	Feed speed
					mm/min.
Standard settings	0	17	90	0	10

ON: Set value for the time to apply a discharge pulse current
OFF: Set value for the time to stop the current after a discharge pulse disappears
Servo voltage: Set value for the mean voltage that is applied between the electrode wire and the workpiece
Machining voltage: Set value for the voltage that is applied when machining pulses are produced
Feed speed: Set value for the maximum transfer speed of the electrode wire position against the workpiece

Under the standard setting conditions, the machining speeds of the conventional product and SUMISPARK Gamma are 0.42 mm/min. and 0.35 mm/min., respectively. The electric conductivity of SUMISPARK Gamma is lower than that of the conventional product. Thus, we considered that the pulse energy would be low under the machining conditions for the conventional product, resulting in failure to reach the melting point of the workpieces. To measure the pulse energy generated during actual machining, we measured the machining current and voltage by the EDM machine, as shown in **Figure 7**. To accurately measure the machining current, we provided insulation between the workpiece and the equipment, except for the current path subject to measurement. We used a digital phosphor oscilloscope manufactured by Tectronix and a probe compatible with 100 MHz or more for measurement. **Figure 8** shows the schematic diagram of the waveforms subject to measurement.

Table 3 shows the waveform analysis results.

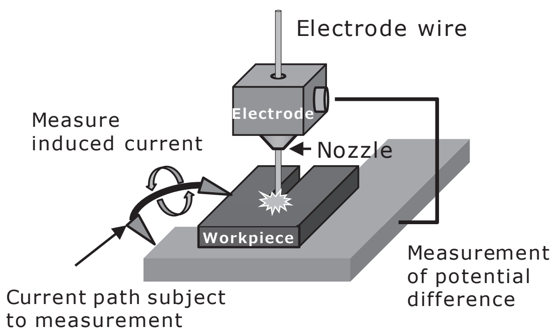


Fig. 7. Schematic diagram of the pulse current measurement technique

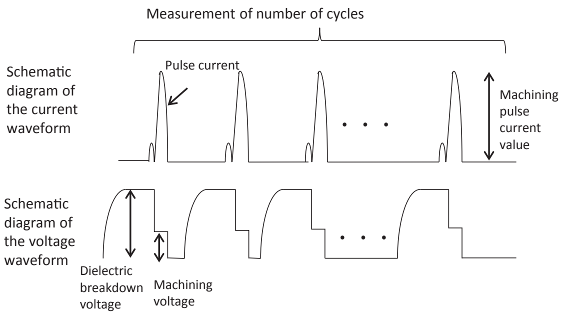


Fig. 8. Schematic diagram of pulse current and voltage waveform

Table 3. Pulse analysis results under the standard conditions

	SUMISPARK Gamma	Conventional product
Machining speed mm/min.	0.35	0.42
Number of discharge cycles ($\times 10^4$ cycles/sec.)	2.25	1.30
Maximum value of the pulse current A/pulse	1.70	2.13
Mean value of the pulse current A/pulse	1.42	1.49
Short circuit rate	7%	15%

The electrical discharge current per pulse of SUMISPARK Gamma is low, but the number of discharge cycles is higher than that of the conventional product. We considered that the machining speed would increase depending on the number of discharge cycles if sufficient energy was given to heat the workpiece to its melting point. Thus, we increased the machining voltage to increase the current value. Among the set values, we reduced the off-time (current suspension time between pulses), decreased the servo voltage (voltage between the workpiece and the electrode wire), and reduced the distance between the workpiece and the electrode wire, in order to set the conditions that were more likely to produce electrical discharges. However, the decreased servo voltage is likely to cause contact between the electrode wire and the workpiece (short circuit). When a short circuit occurs, the electrode wire is physically damaged, increasing the probability of breakage. Thus, we calculated the pulse currents generated by short circuits and arc electrical discharges, respectively, based on the measured pulse waveforms. The short circuit rate was defined and calculated as the percentage of currents generated by short circuits of the total (i.e. number of short circuit pulse currents/ (number of short circuit pulse currents + number of machining pulse currents)). In fact, the electrical discharges became unstable when the short circuit rate exceeded about 60%, resulting in frequent breakage during machining. Thus, we changed the machining condition settings for SUMISPARK Gamma γ and the conventional product, with the upper limit of the short circuit rate set to 55%, to evaluate the machining speed. **Tables 4 and 5** show the machining conditions and pulse analysis results, respectively. These machining settings are hereafter referred to as the multi-discharge settings.

Table 4. Machining conditions (multi-discharge settings)

Machining conditions	ON	OFF	Servo voltage	Machining voltage	Feed speed mm/min.
Multi-discharge settings for SUMISPARK Gamma	0	8	40	2	15
Multi-discharge settings for the conventional product	0	8	80	3	15

Table 5. Pulse analysis results under the multi-discharge settings

	SUMISPARK Gamma	Conventional product
Machining speed mm/min.	0.98	0.77
Number of discharge cycles ($\times 10^4$ cycles/sec.)	3.85	2.60
Maximum value of the pulse current A/pulse	3.08	4.19
Mean value of the pulse current A/pulse	2.56	3.15
Short circuit rate	50%	52%

The increase in machining voltage resulted in increased pulse currents. The decrease in servo voltage resulted in an increased number of discharge cycles and increased machining speed. Thus, SUMISPARK Gamma increased the machining speed up to 0.98 mm/min., which is about three times higher than that of the standard settings. For the conventional product, the lower servo voltage settings also resulted in increased machining speed. However, the machining speed increased only up to 0.77 mm/min. when the short circuit rate reached 52%.

The EDM voltage is constant at about 20–30 V. A servo voltage of 30 V or lower increases the probability of contact between the workpiece and the electrode wire without producing electrical discharges. Thus, a servo voltage of 40 V is considered to be the lower limit to ensure stable operation.

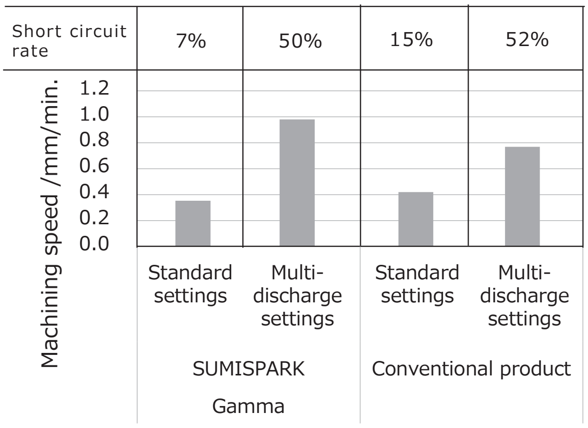


Fig. 9. Machining evaluation results

Figures 10 and 11 show the results of the workpiece surface roughness when SUMISPARK Gamma was used. The first cut was performed based on the standard settings and multi-discharge settings that were discussed above; the second and subsequent cuts were performed based on the conditions that apply when a ø 50 µm tungsten wire is used (settings for AP-200L, an EDM machine manufactured by Sodick Co., Ltd.). We performed machining nine times in total. Measurements

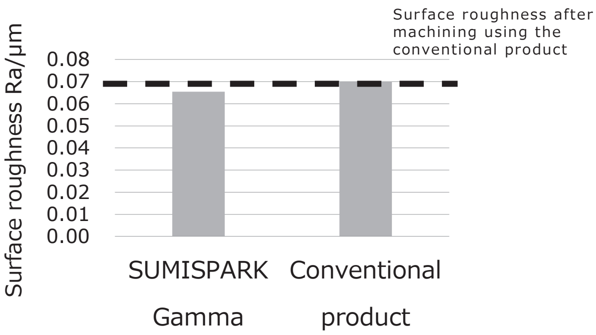


Fig. 10. Surface roughness after machining using SUMISPARK Gamma (Ra)

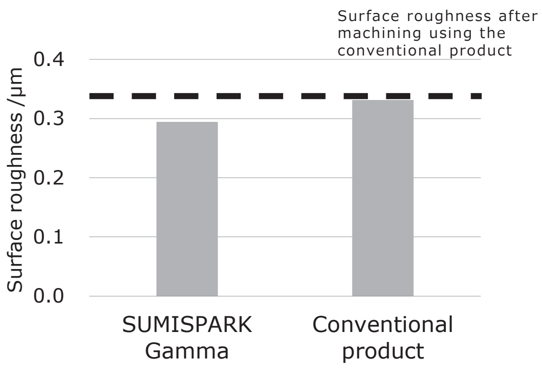


Fig. 11. Surface roughness after machining using SUMISPARK Gamma (Rz)

were conducted using SURFCOM 2800E manufactured by Tokyo Seimitsu Co., Ltd. in accordance with JIS 2001.

Based on the surface roughness measurement results, the machining to "apply a large number of low-energy discharge pulses" (which is a feature of γ-phase brass) is considered to have reduced the fusion area on workpieces per pulse, resulting in increased surface precision.

Figure 12 shows the comparison of the machining tensile strength. We investigated the tension at the time of breakage by increasing the tension in stages during carbide alloy machining (thickness: 10 mm), using the wire EDM machine manufactured by Sodick Co., Ltd. discussed above. To make the conditions more severe for the electrode wires, we conducted experiments by keeping a 10 mm gap between the workpiece and the nozzle (so-called "double float machining").

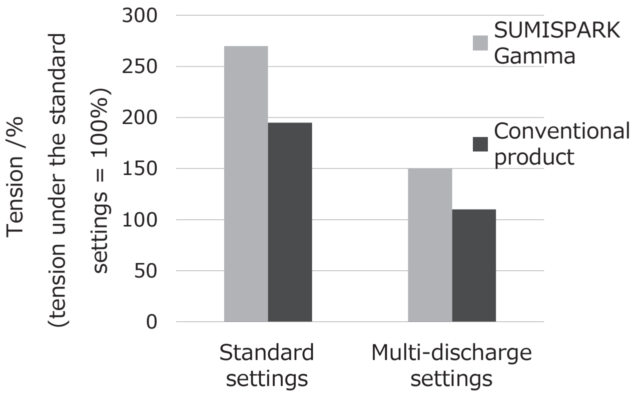


Fig. 12. Machining tensile strength evaluation results

SUMISPARK Gamma can withstand a tension 1.4 times higher than that of the conventional product. The difference is not attributed solely to the difference in wire strength. SUMISPARK Gamma is characterized by high wire strength and high zinc content in the surface layer, this means that less machining heat is transmitted to the steel core and more strength is therefore retained. These characteristics minimize breakage and increases machining stability.

To verify the success rate of automatic wire threading, we conducted automatic wire threading. 10 times using an EDM machine manufactured by Sodick Co., Ltd. to investigate the success rate. As shown in **Figure 13**, a wire was set to be pulled through a hole of ø 0.5 mm in a plate 10 mm away from the nozzle to conduct automatic wire threading. **Figure 14** shows the results.

The results show that the automatic wire threading performance of SUMISPARK Gamma is equivalent to or higher than that of the conventional product.

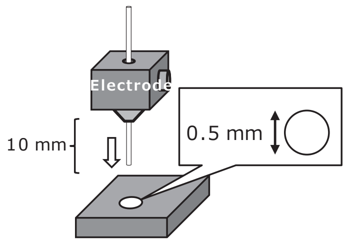


Fig. 13. Schematic diagram of the automatic wire threading evaluation technique

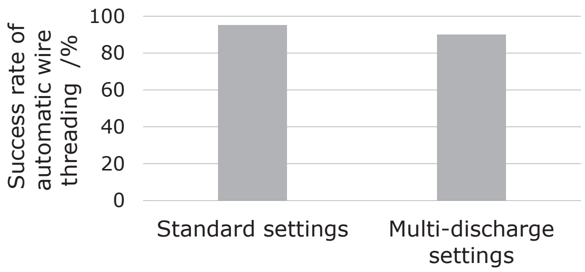


Fig. 14. Evaluation results of the success rate of automatic wire threading

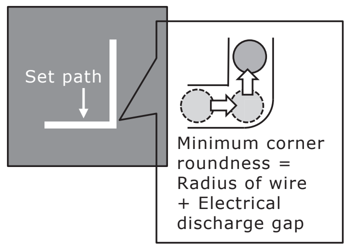


Fig. 15. Schematic diagram of the machining path

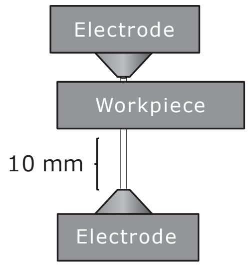


Fig. 16. Schematic diagram of workpiece setting

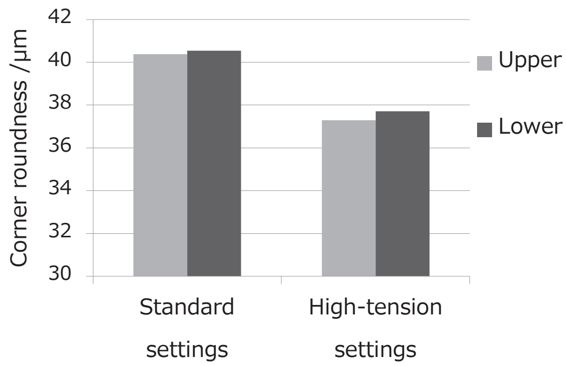


Fig. 17. Corner roundness evaluation results

5. Machining Application Example

SUMISPARK Gamma has been found to be capable of high-speed and high-precision machining and to be characterized by high tensile strength. This section presents a machining application example by taking full advantage of the features of SUMISPARK Gamma. As shown in **Figure 15**, we used SUMISPARK Gamma for machining at a right angle and measured the precision of corner roundness. We used the same EDM machine and workpiece material as discussed above. As shown in **Figure 16**, the nozzle of the EDM machine was placed in close contact with the top part of the workpiece and provided a 10 mm gap at the bottom, in order to make a significant difference at the top and bottom of the workpiece. A comparison was made between the standard tension settings and the high tension settings (a 25% increase in the tension for the second and subsequent cuts). Regarding the machining conditions, multi-discharge settings applied only to the first cut, and the standard setting conditions established by Sodick Co., Ltd. applied to the second and subsequent cuts (except for the tension settings). **Figure 17** shows the results.

High-tension machining using SUMISPARK Gamma can minimize corner roundness and achieve machining precision that is higher than ever before.

6. Future Prospects

This paper presented the workability evaluation results on tungsten carbide (a conductive material) using SUMISPARK Gamma. We will endeavor to enter the market of smaller diameter wires (≤ ø 40 μm) by taking full advantage of the high wire strength. It has been reported that EDM is possible on semiconductors (e.g. SiC) and nonconductors (e.g. ceramics).[4] We will apply SUMISPARK γ on these materials and enable machining by optimizing the machining conditions using the techniques presented in this paper.

7. Conclusion

The use of SUMISPARK Gamma achieves high-speed machining, increases workpiece surface precision, and ensures stable machining. These characteristics increase the equipment operation time, reduce wire consumption, increase productivity, and cut the manufacturing cost. Sumitomo (SEI) Steel Wire Corp. fully launched sales of SUMISPARK Gamma in January 2015, and the product has been highly evaluated by customers. We expect that SUMISPARK Gamma can meet every need in precision parts machining.

• SUMISPARK is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

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