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Optimization of Machining Parameters for Wire-Cut EDM on Various Nickel Alloys–A Review

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A B S T R A C T

Wire-cut Electric Discharge Machining (WEDM) is a non-conventional machining process in which electrical conductive, harder materials can be machined like nickel-based alloys, metal matrix composites, ceramic-based materials etc. with higher precision as per requirement. Nickel-based alloys exhibit more creep strength and more mechanical strength at higher temperatures, excellent surface condition, oxidation and corrosion resistance. These nickel-based alloys are majorly used in aerospace applications and furnace equipment. In this present paper, various machining parameters are studied with different optimizing techniques such as Taguchi orthogonal technique, GRA, and PCA. The parameters like pulse on time, pulse off time, peak current, servo voltage, wire diameter, wire feed rate and wire tension are considered to study MRR, Wire wear ratio, surface roughness, Kerf, microhardness and SEM-EDX images. ANOVA technique was used to study the major contribution of process parameters while studying MRR, surface roughness and Kerf width.

Keywords: WEDM, Taguchi orthogonal technique, GRA, PCA, Kerf, SEM-EDX, ANOVA

INTRODUCTION:

Wire-cut Electric Discharge Machining (WEDM) is an electro-thermal machining process in which submerged work material is cut by the wire electrode during pulse on time, the spark is generated in between work and tool and the work material is melted and vaporized quickly. Different types of dielectric materials such as de-ionized water, paraffin oil, and transformer oils may be used for flushing, cooling and removing the debris from the work material. Zinc, copper-coated brass wire, annealed brass wire and abrasive-coated brass wire are used as cutting tools. The diameter of the electrode wire ranges from 0.1 to 3mm based on requirement.

The various types of nickel-chromium alloys are Nimonic alloy 75, Nimonic alloy 80A, Nimonic alloy 90, Nimonic alloy 263, Inconel 625, Inconel 706, Inconel 718, Inconel 825 and waspaloy etc. These alloys are widely used in gas turbine parts, aerospace, marine and furnace applications.

Nimonic alloy 75 chemical composition: Nickel-77.7%, Chromium-18-20%, Iron-5%max, Manganese-1% max, Silicon 1% max, Titanium 0.2 - 0.6%,carbon-0.08 -0.15%.

Nimonic alloy 80A chemical composition: Nickel-77.05%, Chromium-18.39%, Iron-0.63% max, Manganese-0.2% max, Silicon 0.19% max, Titanium 1.92%.

Nimonic alloy 90 chemical composition: Nickel-77.3%, Chromium-21%, Iron-1.5%max, Manganese-1% max, Silicon- 1% max, Titanium- 3%,carbon-0.13%.

Nimonic alloy 263 chemical composition: Nickel- 49%, Chromium-21%, Cobalt-21%, Molybdenum-6.1%, Iron-0.7%, Manganese-0.6%, Aluminium-0.6%

Inconel 706 chemical composition: Nickel-41.5%,Chromium-16%, Iron-40%, Nb-2.9%,Al-0.2%, Manganese-0.2 % ,Silicon 0.2 %, Titanium 1.8% ,carbon-0.03%.

Inconel 718 chemical composition: Nickel-54.48%, Chromium-17.5%, Iron-22.3%max, Nb-4.9 % max, Titanium 0.96%, Al-0.66%.

Inconel 825 chemical composition: Nickel-37.5%, Chromium-22.8%, Iron-32.2%max, Titanium 0.86%, carbon-0.016%.

Waspaloy chemical composition: Nickel-58%, Chromium-21%, Co-13%, Iron-2%max, Manganese-1% max, Silicon- 0.75% max, Titanium -351%, Chromium-20%, Al-0.6%max, Mo-6.1% max, Silicon 0.4%max, Titanium 2.4% max,carbon-0.08%.

Inconel 625 chemical composition: Nickel-58%,Chromium-21.5%, Iron-5%max,Mo-9%, Manganese-0.**5%** max,**Silicon-0.5%** max, **Titanium-0.4% ,carbon-0.1%**, **Al -1.6%**,**Cu-0.5%**.

Inconel 706: Nickel- 39-44%, Iron-38%, Chromium 14.5-17.5%; Niobium-2.50-3.3%.

Incoloy 800: Nickel-34.56 %,Chromium-19-23%, Manganese-0.46%, Silicon 0.25%, carbon- 0.05%,Al-0.25%, Titanium -0.314%.

Monel 400: Nickel- 63%, Copper-34% max, Iron-2.5%, Silicon-0.5%, Carbon-0.3 %, Manganese-2%, Sulfur-0.024%.

APPLICATIONS OF VARIOUS NICKEL ALLOYS:

Table1. Applications of various Nickel alloys

Name of Nickel alloy	Applications
Nimonic alloy 75	Furnace and heat treatment applications, Aerospace and gas turbine parts.
Nimonic alloy 80A	Aerospace parts, jet engine nozzles, nuclear and Automobile exhaust valves.
Nimonic alloy 90	Gas turbine, Automobile exhaust valves, Die-casting parts and Nuclear parts.
Nimonic alloy 263	Furnace parts, Jet engine parts and Gas turbine parts.
Inconel 625	Heat exchanges, Heating elements, Carburizing equipment, Sheathing and nuclear applications
Inconel 706	Gas turbine shafts, turbine discs, cases, and fasteners.
Inconel 718	Jet engines, High-speed airframe parts, Turbine parts, Marine and Mining parts, Oil, gas and Petrochemical applications.
Incoloy 800	Submarine parts, quick-disconnect fittings, Aerospace parts, Nuclear parts
Monel 400	Marine parts, Heat exchangers, Crude oil distillation stills, Boiler feed water heaters and Chemical processing plants.
Waspaloy	Gas turbine components, Aircraft, missile parts and Compressor parts
Hastelloy X	Petrochemical equipment, gas turbine parts, Aircraft parts, Furnace parts, and Chemical processing applications.

LITERATURE REVIEW:

Amitesh Goswami et al conducted experiments on Nimonic 80A of size 8mm x 8mm x 25 mm on WEDM using a brass electrode of 0.25mm by considering Ton, Toff, peak current(IP), wire feed rate, wire tension and spark gap voltage as process parameters and concluded that Ton and Toff are the most significant factors for MRR. Ton x T off, Ton x IP gave higher contribution on WWR and recast layer thickness increased as an increase in Ton and Peak current [1].

Sachin Ashok Sonawane et al conducted experiments with 5-axis ePULSE-40 sprint cut WEDM on Nimonic alloy 75 work material of size 10mm x10mm x 5 mm thickness by a brass electrode of wire diameter 0.25mm at a flushing pressure of 15 kg/cm2.The conductivity of the dielectric fluid is maintained at a constant value of 20μs/cm at 220C. The value of the servo feed is maintained at 2120 units. L27 Taguchi's orthogonal array is used to optimize the process parameters for MRR and Surface roughness and thickness of the recast layer [2].

U. A. Kumar et al performed operations on a wire-cut EDM machine (Electronica Sprint cut) of Electronica Machine Tools Ltd. on Nimonic alloy 75 of size 100mm x 50 mm x 2 mm thickness, a brass electrode of wire diameter 0.25mm used as an electrode. L9 Taguchi's orthogonal array is utilized to optimize the process parameters for MRR, Kerf width and Kerf taper [3].

Subrahmanyam et al performed experiments on a wire-cut EDM machine with a particular design fixed column, moving table type with a size of the workpiece 250 x 350 mm, with linear interpolation, power supply 3 phase, AC 415 V, 50 Hz. The work material is size 30mm x 15 mm x 2mm of Inconel 625 sheet. A brass wire of diameter 0.25 mm is used for machining the material. The brass wire is tensioned between the lower and upper guides to obtain better accuracy. Deionized water is used as a dielectric fluid. Surface roughness analyzer was used to measure the Surface roughness value [4].

Vinayak N Kulkarni et al did experiments on Ni-Ti superelastic alloy. The work sample was machined with 0.25mm brass wire on Electronica eco cut cells-15 CNC Wire EDM and showed that Pulse on time and servo voltage are the main two parameters to get a good surface finish. The experimental results show that the value of surface roughness increases with pulse on time and servo voltage and decreases with pulse time off [5].

Harvinder Singh et al designed a mathematical regression model of wire-cut EDM parameters for surface roughness during the machining of Nimonic75 alloy using the response surface methodology (RSM) and desirability function approach for multi-response optimization. Using ANOVA, concluded that the Ton is the most significant parameter affecting the surface roughness (Ra) followed by peak current. The optimal parameters for minimum surface roughness are a Ton 0.6μs, T off 46μs, servo voltage 55 V and peak current 80A. The confirmation results show the goodness of the developed model.EDS results show that elements like O, Zn and Cu are migrated on the machined surfaces. Surface morphology was studied through SEM [6].

Payal Deb et al performed an investigation on Inconel 800 using WEDM. Peak current, pulse on time and pulse off time were taken as process parameters to optimize Kerf width and average. Surface roughness, total surface roughness and wire consumption. Pulse on time is the major effecting parameter when compared to pulse off time and peak current. According to ANOVA, pulse on time contributed more to Kerf width, average. Surface roughness, total surface roughness and wire consumption [7].

Abhilash et al conducted experiments on Inconel 718 material with size 10 mm X 10mm with one side semicircular profile machined on Electronica Eco-cut wire-EDM by taking wire diameter of 0.25mm zinc coated brass wire. T on, Toff, and Servo voltage are considered process parameters. For studying microstructural analysis and elemental analysis, Zeiss Gemini SEM 300 field emission scanning electron microscope and Energy dispersive X-ray spectroscopy (EDS) are used respectively. Surface topology was observed by AEP Nanomap1000 Noncontact 3D surface [8].

Divya Marelli et al performed machining on Incoloy 800 by ELECTRONICA Sprint cut ELPULs 40A DLX wire cut EDM. A brass electrode of diameter 0.25mm was used to cut the specimen into 27 parts of size 12mmx12mmx6mmthick. The Taguchi L-27 orthogonal array was used to optimize MRR and surface finish. Pulse on time, pulse off time, Gap voltage and Peak current are the parameters considered during the machining process [9].

Anoop Kumar et al conducted experiments on Inconel 625 by machining on wire-cut EDM. Brass wire was used as the electrode material and considered the Pulse-ON, Pulse-OFF, Wire feed rate, Peak current, Servo voltage and Flushing pressure as process parameters to optimize surface roughness and Kerf width. Taguchi L27 orthogonal array was used as an optimization technique and ANOVA was used to find the most influenced parameters. SEM analysis was conducted to observe the microstructure of Inconel 625 samples [10].

Alok Kumar et al studied an Inconel 718 plate of size 120mm x 100 mm x 6 mm by machining on EXCETEK EX 40WEDM by considering Open current voltage, Pulse time on, wire fee rate and wire tension as process parameters. By using Regression analysis and Taguchi's L-9 Orthogonal analysis final results are optimized [11].

N.E. Arunkumar et al: Investigated to optimize the machining parameters on Monel 400 material using

BAOMA DK7732 four axes CNC Wire cut EDM. A Molybdenum wire of diameter 0.18 mm was used as an electrode material. Deionized water of conductivity 20mho and flushing pressure 7kg/cm2 was used to flush the debris while machining. Peak current, wire feed rate, pulse on time and pulse off time are considered to optimize MRR, Dimension Deviation and spark gap. Taguchi L-27 orthogonal array was a technique used for optimization [12].

RESULTS AND DISCUSSIONS:

Surface roughness of 1.71μm optimized by the combination of Peak current (110A), pulse on time (110μs), pulse off time (60μs), wire feed rate (2 m/min), servo voltage (40v) and flushing pressure (5kg/cm2). Kerf width of 0.2888mm, optimized by the combination of peak current (110A), pulse on time (110μs), pulse off time (50μs), wire feed rate (2m/min), servo voltage (20V) and flushing pressure(5kg/cm2) as shown in fig1[10].

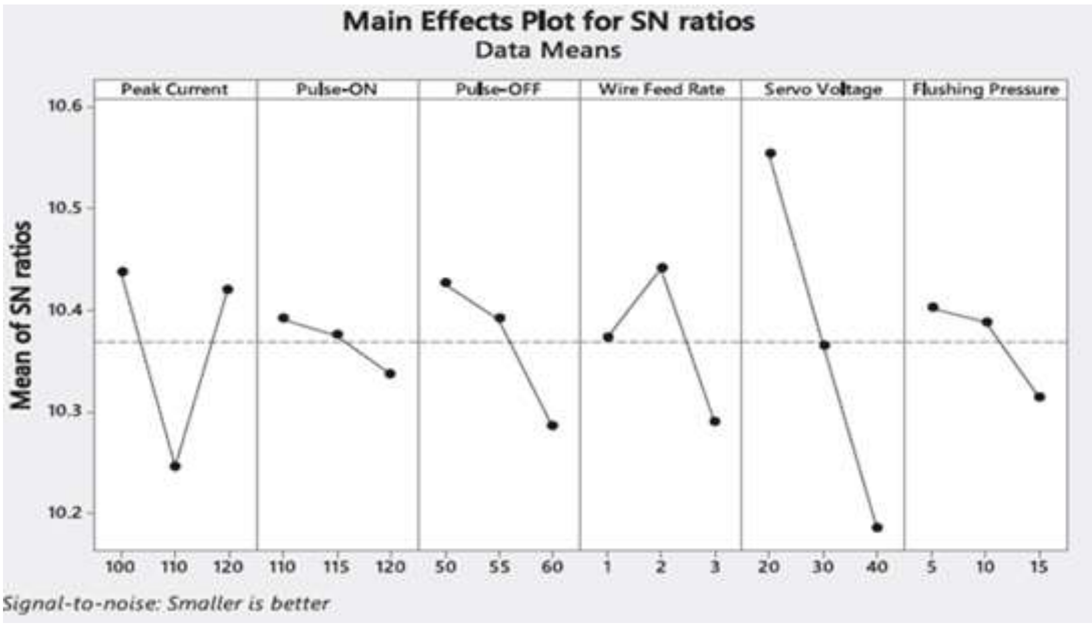

Fig1. S/N Ratio of Kerf Width graph and the combination levels [10]

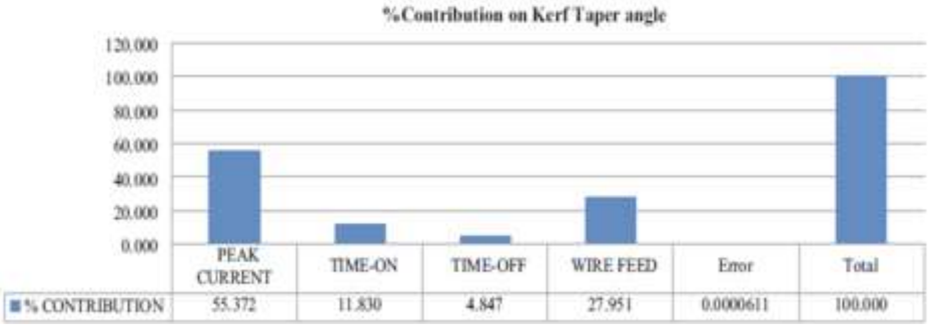

Fig.2 Percentage contribution -Kerf taper angle with respect to ANOVA [3]

From the above analysis Peak current is the most influencing parameter on Kerf Taper angle. Kerf Taper angle increases when pulse on time increases and Kerf Taper angle decreases when pulse on time increases. Kerf Taper angle increases When the Peak current increases. The discharge current, voltage and Ton are influenced by material removal rate and surface roughness of Inconel 625 machined component with brass electrode [4].

Table2. Applications of various Nickel alloys [4]

Response table.

S.NO	FACTOR A	FACTOR B	FACTOR	MRR	Ra
	Ton (μs)	Toff (μs)	C SV (volts)	(g/min)	(μm)
1	125	30	15	0.06541	3.844
2	125	35	20	0.06593	4.122
3	125	40	25	0.06567	4.070
4	130	30	20	0.06567	3.898
5	130	35	25	0.06580	4.000
6	130	40	15	0.06593	3.850
7	135	30	25	0.06567	4.128
8	135	35	15	0.06593	4.394
9	135	40	20	0.06580	4.622

The optimized value of Material Removal Rate,0.01719 g/min, obtained after machining of Nimonic alloy 75 are at 220amp peak current, 110μs Ton, 53μs, T off and 1 m/min wire feed rate. 0.2792 mm of Kerf width optimized at 180amp peak current, 110 ms Ton, 63μs T off and 3 m/min wire feed rate. The optimized value of Kerf Taper angle 0.0050, as obtained at 180amp peak current, 110μs, Ton 53μs T off and 1 m/min wire feed rate. In the microstructure of the samples, Craters, spherical globules, a Lump of debris and micro holes were observed in a scanning electron microscope at 10,000 X magnification, Fig 4.

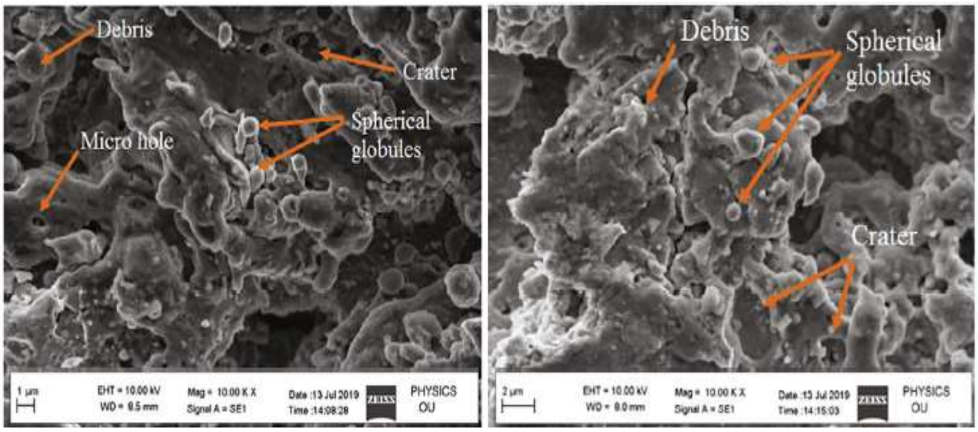

Fig4. Micro Structures of Machined of Nimonic alloy 75 [3]

Material removal rate increases with an increase in Pulse on time and decreases with pulse off time, up to 40V of servo voltage MRR increases but further increase in servo voltage decrease. To get more MRR, a higher value of Ton and, a lower value of T off are required, higher value of Ton and medium values of SV are needed [5].

Using a3D non- contact type profilometer the surface morphology compared at least stable and most stable conditions, the results are shown below.

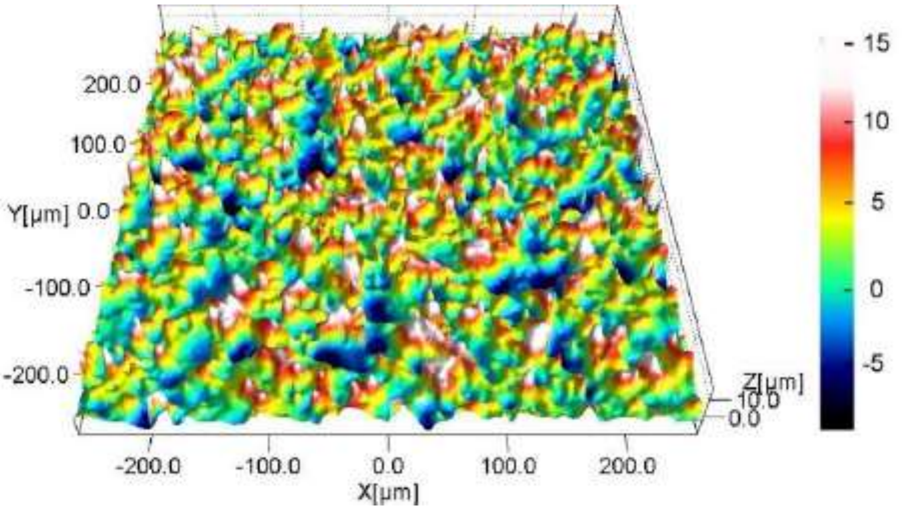

Fig.5. 3D surface morphology image at least stable condition [8]

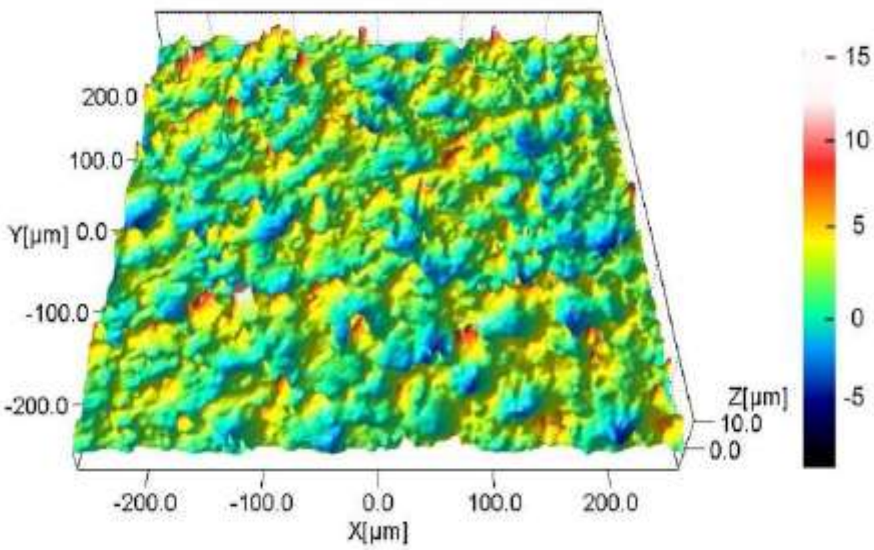

Fig6. 3D surface morphology image at stable condition [8]

By the Taguchi optimization technique, surface roughness was optimized at Ton 100µs, T off 42µs, Gap voltage 35 V, and Peak current 165A. From the gray relation analysis, the optimum values of both surface roughness and MRR are obtained at Ton120µs, T off 54µs, Gap voltage 45 V and Peak current 180 Amp [9].

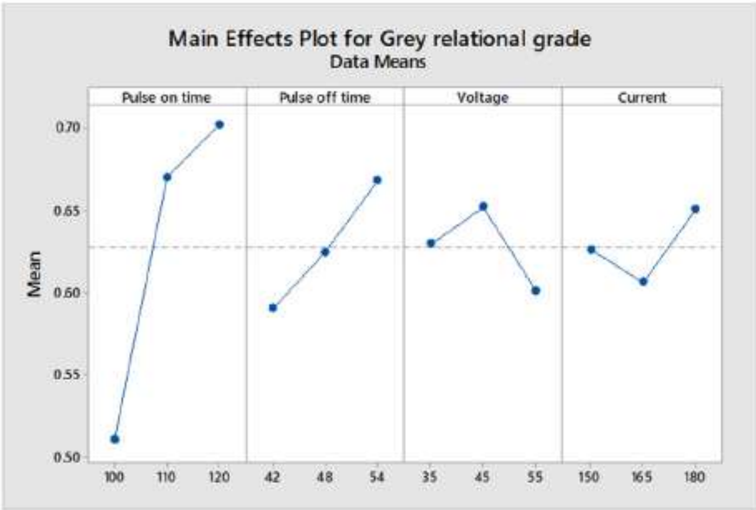

Fig.7 Main effects plot for grey relational grades [9]

From the Analysis of variance, it was shown that Ton is the highest influencing parameter followed by Open circuit voltage and wire feed rate. Wire tension showed the least influence on MRR. For Surface roughness Pulse on time has shown the highest influence and open circuit voltage has shown the least influence [11].

The recast layer for the machined sample at Pulse time on (Ton) 0.6µs, Pulse time (Toff) 14µs, peak current (IP) 120A, wire off set (WO) 0.12 mm, a foamy and porous layer was observed along the machined surface. The average recast layer thickness was observed to be 22µm as shown in fig 8.

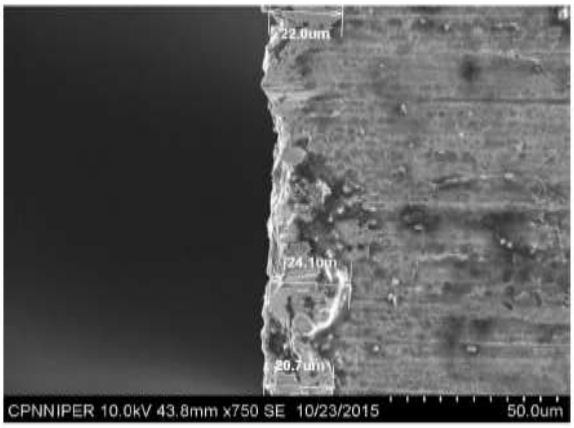

Fig.8 Recast layer of the machined sample (Ton: 0.6µs, T off: 14µs, IP: 120A, WO: 0.12 mm [11].

By continuous flushing of molten metal with dielectric fluid, the percentage of Ni and Cr was decreased. It is observed that small amount Carbon was deposited on the work material because of improper flushing while machining. And at higher temperature some amount of Cu was transferred from brass electrode to work piece.

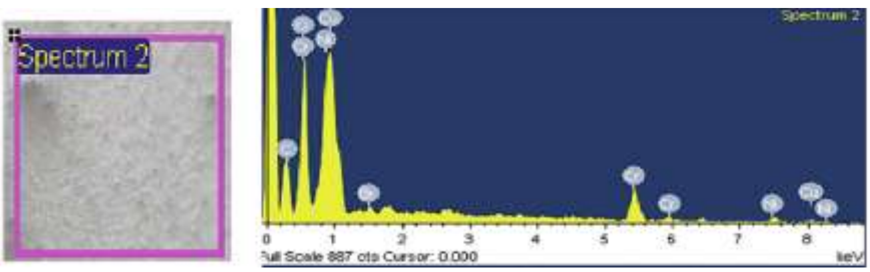

Fig.9 EDS Composition Result at spectrum point and graph for Sample-6[3].

CONCLUSION:

1. By increasing the value of pulse on time, more heat energy developed and that leads to an increase in MRR, Wire wear rate, Kerf width, surface roughness and Kerf taper angle.
2. Decreasing the pulse of time leads to an increase in cutting speed and more amount of material can be removed but the load increases on wire material and finally wire is broken.
3. As the increase in Peak current, MRR and surface roughness both are increased.
4. Increase in wire feed rate, more and more wire material is consumed, and thus machining cost increases. A decrease in wire feed rate leads to breakage of wire at higher cutting speeds.
5. An increase in wire tension gives a straight cut, but as the tension increases, the wire electrode may be broken.
6. Surface finish can be increased by providing negative tool polarity rather than by giving positive tool polarity. More amount of carbon is deposited in positive tool polarity than in negative tool polarity.
7. For effective machining, a proper rate of dielectric fluid flushing is required.

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