 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

A Comparative Optimization on Process Parameters of Wire Electrical Discharge Machining of Inconel-690 using Taguchi Method

[1]R. K. Thakur, [2]N. Selvaraj, [3]S. Mohanty
[1,2]Dept. of Mechanical Engineering, National Institute of Technology, Warangal, India
[3]Veer Surendra Sai University of Technology, Burla, Odisha

Abstract
In the present paper, wire electrical discharge machining is used for the machining of nickel-chromium based alloy of Inconel 690 with the application of two types of wire as brass and zinc coated brass wire. A comparative study was performed by varying the parameter like pulse on time, pulse off time, peak current and servo voltage for the optimization of kerf taper, material removal rate and surface roughness. Results showed that zinc coated brass wire gives 6.53% higher kerf width, 19.23% higher material removal and 14.49% higher surface roughness than brass wire and peak current is the most dominating factor for all performances of brass and zinc coated brass wire.

Keywords
MRR, SR, KW, Taguchi Method, ANOVA

I. Introduction
Mechanical industry is focusing on the technology which provides better surface finish and dimensional accuracy. Since conventional machining resulted in bad surface texture, burn-out zone and hence non-conventional machining like Wire EDM provides better alternative for the manufacturing industry to achieve better surface texture and accuracy. In Wire EDM, the accurate position of workpiece and wire feeding system are established. A series of spark is produced on material with the help of wire and no contact is established between work material and wire. Coolant such as de-ionized water is supplied continuously on the machining zone with the use of nozzle. It also removes eroded material from the machining zone.
Several researchers have optimized responses such as Material Removal Rate (MRR), Surface Roughness (SR) and Kerf Width (KW). Prasad et al. [1] found that pulse on time has the highest effect on KW and SR while machining of titanium by using brass wire. Shardul et al. [2] machined graphite Plate with the application of brass wire by varying pulse on time, pulse off time, wire tension and peak current to optimize SR and MRR. It was found that wire tension has more effect on MRR and SR. Karsh and Singh [3] machined Inconel 625 with the application of copper wire by varying pulse on time, pulse off time and peak current.It was found that SR increases as pulse on time increases and pulse on time is the most significant factor. Dhale and Kulkarni [4] used Inconel 718 as work material and varied pulse on time, pulse off time, wire material, wire tension, wire feed and flushing pressure to optimize SR and MRR. MRR mainly affected by pulse on time and wire material. Dabade and Karidkar [5] used Inconel 718 and zinc coated brass wire by varying pulse on time, pulse off time, peak current, wire feed, wire tension and spark gap set voltage to optimize MRR, SR, KW and dimensional deviation. It was observed that pulse on time is the most important factor for all the responses.
Sreenivasa and Venkaiah [6] machined Inconel 690 with the application of zinc coated brass wire by varying pulse on time, pulse off time, servo voltage and peak current. Thick plate of 6.5 mm thickness was used to produce 10mm hole and ANN model was used to predict the circularity error. It was found that circularity error increases as pulse on time and pulse off time increases whereas circularity error decreases as servo voltage increases. Rodge et al. [7] machined Inconel 625 with the application of brass wire by varying pulse on time, pulse off time, wire tension, wire feed, upper flush and lower flush to investigate wire wear, kerf width and hardness. Kerf width was mostly affected by pulse on time and wire wear was mostly affected by wire feed while hardness was mostly affected by pulse off time. It was found that KW increases as pulse on time increases which resulted in lower wire wear. Rane and Prakash [8] used Inconel 800 as work material and molybdenum as wire material. Pulse on time, pulse off time, servo voltage, bed speed and peak current were selected as process parameter to investigate SR and MRR. Peak current has the highest effect on MRR whereas pulse on time has the highest effect on SR.
In the present investigation, comparative study is done by using brass and zinc coated brass wire to machine Inconel 690 on Wire EDM. Process parameters as pulse on time, pulse off time, servo voltage and peak current are varied to optimize performances like KW, MRR and SR.

II. Material Selection
Inconel-690 (Nickel-Chromium alloy) is used as work material in the present experimental investigation. Chemical composition of Inconel 690 is shown in Table 1.

Table 1: Chemical Composition of Inconel 690

INCONEL 690	
Elements	Specifications (%)
Nickel	57.74
Chromium	28.72
Aluminium	0.96
Titanium	0.27
Iron	8.70
Silicon	0.66

III. Experimental Setup
All the experiments were performed on ELECTRONICA Wire cut machine which is shown in fig. 1. Machining operation was performed on a rectangular block of Inconel 690 with length

100 mm, width 150 mm and thickness 10mm. Brass and Zinc coated brass of 0.25mm thickness were used as electrode. The cuts of 20 mm depth along the length were taken for experimental study.

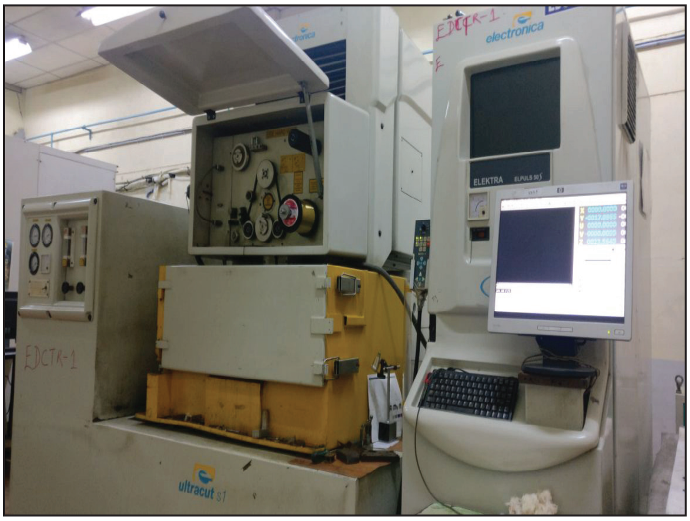

Fig. 1: CNC Electronica Wire EDM Machine

IV. Experimental Design

In this experiment pulse on time, pulse off time, peak current and servo voltage were used as process parameter to investigate KW, MRR and SR. Each input process parameter was assigned three level values and the range of parameters were kept as pulse on time (102-110 µs), pulse off time (57-63 µs), peak current (10-12 A) and servo voltage (40-80 V) as shown in Table 2. Minitab 17 Software was used for orthogonal array design as shown in Table 3.

Table 2: Level Values of Input Parameter

S. No	Parameters	Level-1	Level-2	Level-3
1	Pulse on time (A)	102	106	110
2	Pulse off time (B)	57	60	63
3	Peak Current (C)	10	11	12
4	Servo Voltage (D)	40	60	80

Table 3: Design of L9 Orthogonal Array

S. No	Pulse on time	Pulse off time	Peak Current	Servo Voltage
1	102	57	10	40
2	102	60	11	60
3	102	63	12	80
4	106	57	11	80
5	106	60	12	40
6	106	63	10	60
7	110	57	12	60
8	110	60	10	80
9	110	63	11	40

A. Kerf Width (KW)

Kerf is the amount of the material wasted during machining. During machining the main aim is to maximum MRR and minimum Kerf width. It is measured by optical micrometer.

B. Material Removal Rate (MRR)

The material removal rate is the amount of the material removed per minute.
Material removal rate is calculated by using the formula $MRR = V/t$ mm^3/min, Where V = Volume of material and t = Time of machining

C. Surface Roughness (SR)

Roughness shows the texture of a surface. Surface roughness tester is used to measure surface roughness as shown in fig. 2.

Fig. 2: Surface Roughness Tester

V. Result and Discussion

A. For Brass Wire

By performing the experiment using brass wire, experimental data of KW, MRR and SR are obtained. Results are analyzed using S/N ratios graph, response effect and ANOVA with the help of Minitab 17 Software. Minitab 17 software helps to calculate S/N ratio according to response value as shown in Table 4 and provides the order of dominating factor for KW, MRR and SR as shown in Table 5, Table 7 and Table 9 respectively and percentage contribution of each input parameter using ANOVA analysis for KW, MRR and SR as shown in Table 6, Table 8 and Table 10 respectively.

Table 4: Experimental value of KW, MRR and SR

S. No.	Time (Min)	KW (mm)	S/N Ratio KW	MRR (mm3/ min)	S/N Ratio MRR	SR (µm)	S/N Ratio SR
1	270	0.5174	5.723	0.383	-8.331	0.85	1.411
2	44	0.4293	7.344	1.951	5.806	0.67	3.478
3	48	0.4159	7.620	1.934	4.775	0.75	2.498
4	40	0.4476	6.982	2.238	6.997	0.85	1.411
5	30	0.4253	7.426	2.835	9.052	0.94	0.537
6	315	0.6173	4.190	0.391	-8.136	1.11	-0.906
7	65	0.4418	7.095	1.359	2.666	0.84	1.514
8	335	0.5423	5.315	0.323	-9.797	0.92	0.724
9	25	0.4331	7.268	3.464	10.793	0.62	4.152

Table 5: Response Table of S/N Ratios for KW

Level	Ton	Toff	Peak Current	Servo Voltage
1	6.896	6.600	5.076	6.806
2	6.199	6.695	7.198	6.210
3	6.560	6.360	7.381	6.639
Delta	0.697	0.336	2.304	0.596
Rank	2	4	1	3

Table 6: Analysis of Variance for KW

Degree of Freedom	Sum of Square	Variance	Contribution (%)
2	0.0027	0.0013	7.15
2	0.0009	0.0004	2.46
2	0.0322	0.0161	84.47
2	0.0022	0.0011	5.92
8	0.0382		100

Table 7: Response Table of S/N Ratios for MRR

Level	Ton	Toff	Peak Current	Servo Voltage
1	1.0686	0.440	-8.7550	3.8380
2	2.6376	1.6871	7.8657	0.1121
3	1.2209	2.7960	5.8164	0.9770
Delta	1.5689	2.3520	16.6208	3.7259
Rank	4	3	1	2

Table 8: Analysis of Variance for MRR

Degree of Freedom	Sum of Square	Variance	Contribution (%)
2	0.2560	0.12802	2.5
2	0.5576	0.27879	5.44
2	7.8445	3.92227	76.55
2	1.5888	0.79438	15.51
8	10.2469		100

Table 9: Response Table of S/N Ratios for SR

Level	Ton	Toff	Peak Current	Servo Voltage
1	2.4630	1.4459	0.4098	2.0337
2	0.3475	1.5801	3.0141	1.3622
3	2.1303	1.9148	1.5169	1.5449
Delta	2.1154	0.4689	2.6043	0.6716
Rank	2	4	1	3

Table 10: Analysis of Variance for SR

Degree of Freedom	Sum of Square	Variance	Contribution (%)
2	0.07548	0.03774	43.16
2	0.00068	0.00034	0.39
2	0.09135	0.04567	52.26
2	0.00735	0.00367	4.02
8	0.17488		100

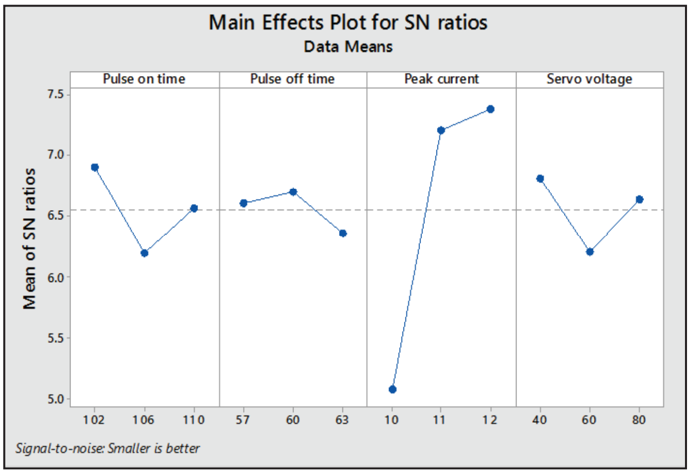

Fig. 3: Effect of Parameters on KW

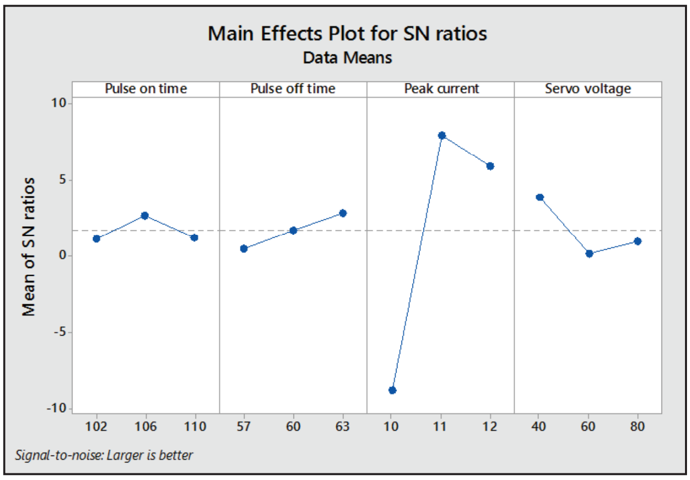

Fig. 4: Effect of Parameters on MRR

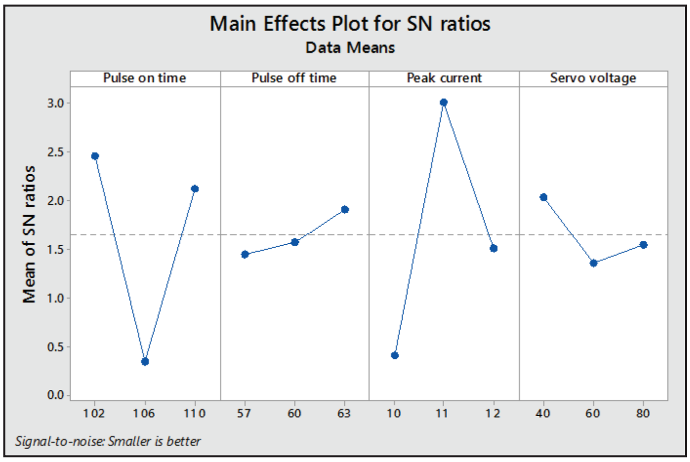

Fig. 5: Effects of Parameters on SR

The aim of the experiment was to obtain the optimum factor level value which strongly affects the machining performances. From mean of S/N ratio for kerf width, it was found that peak current has the highest effect followed by pulse on time, servo voltage and pulse off time. Optimum condition for kerf width (smaller is better) was found at A1-B2-C3-D1 as shown in fig. 3. From mean of S/N ratios for MRR, It was found that peak current has highest on MRR. Optimum condition for MRR (larger is better) was found at A2-B3-C2-D1 as shown in fig. 4. From mean of S/N ratios for SR, it was found that peak current has the highest effect on SR. Optimum condition for surface roughness (smaller is better) was at A1-B3-C2-D1 as shown in fig. 5.

1. Confirmation Experiment

At optimum condition experiments are performed and compared with predicted value given by Minitab 17 software for KW, MRR and SR as shown in Table 11, Table 12 and Table 13 respectively. However error can be minimized with more number of experimental run.

Table 11: Result of Confirmation Experiment for KW

	Predicated Value	Experimental Value	% error
Optimal Level	A1-B2-C3-D1	A1-B2-C3-D1	
KW (mm)	0.3827	0.4175	
S/N Ratio for KW	8.1228	7.5868	6.6

Table 12: Result of Confirmation Experiment for MRR

	Predicated Value	**Experimental Value**	**% error**
Optimal Level	A2-B3-C2-D1	A2-B3-C2-D1	
MRR (mm^3/min)	3.5706	3.7028	
S/N Ratio for MRR	12.2102	11.3706	6.87

Table 13: Result of Confirmation Experiment for SR

	Predicated Value	**Experimental Value**	**% error**
Optimal Level	A1-B3-C2-D1	A1-B3-C2-D1	
SR (µm)	0.583333	0.59	
S/N Ratio for SR	4.48486	4.5829	2.14

B. For Zinc-Coated Brass Wire:

By performing the experiment using zinc coated brass wire, experimental data of KW, MRR and SR are obtained. Results are analyzed using S/N Ratios graph, response effect and ANOVA with the help of Minitab 17 Software. Minitab 17 software helps to calculate S/N Ratio according to response value as shown in Table 14 and provides the order of dominating factor for KW, MRR and SR as shown in Table 15, Table 17 and Table 19 respectively and percentage contribution of each input parameter using ANOVA analysis for KW, MRR and SR as shown in Table 16, Table 18 and Table 20 respectively.

Table 14: Experimental value of KW, MRR and SR

S. No.	**Time (Min)**	**Kerf Width (mm)**	**S/N-KW**	**MRR (mm^3/min)**	**S/N-MRR**	**SR (µm)**	**S/N-SR**
1	275	0.5219	5.6482	0.3975	-8.0133	1.32	-2.411
2	40	0.4395	7.1408	2.1975	6.8386	1.31	-2.345
3	40	0.4600	6.7448	2.3000	7.2346	1.41	-2.984
4	75	0.4690	6.5765	1.2506	1.9424	1.36	-2.670
5	27	0.4376	7.1784	3.2414	10.2147	0.97	0.264
6	170	0.5334	5.4589	0.6275	-4.0477	1.52	-3.636
7	22	0.4380	7.1705	3.9818	12.0016	0.71	2.974
8	162	0.5490	5.2085	0.6777	-3.3793	1.12	-0.984
9	60	0.4651	6.6490	1.5503	3.8083	0.91	0.819

Table 15: Response Table of S/N Ratios for KW

Level	**Ton**	**Toff**	**Peak Current**	**Servo Voltage**
1	6.511	6.465	5.439	6.492
2	6.405	6.509	6.789	6.590
3	6.343	6.284	7.031	6.177
Delta	0.169	0.225	1.593	0.413
Rank	4	3	1	2

Table 16: Analysis of Variance for KW

Degree of Freedom	**Sum of Square**	**Variance**	**Contribution (%)**
2	0.000159	0.000080	1.04
2	0.000215	0.000107	1.40
2	0.014096	0.007048	92.08
2	0.000838	0.000419	5.48
8	0.015308		100

ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

Table 17: Response Table of S/N Ratios for MRR

Level	Ton	Toff	Peak Current	Servo Voltage
1	2.020	1.977	-5.147	2.003
2	2.703	4.558	4.196	4.931
3	4.144	2.332	9.817	1.933
Delta	2.124	2.581	14.964	2.998
Rank	4	3	1	2

Table 18: Analysis of Variance for MRR

Degree of Freedom	Sum of Square	Variance	Contribution (%)
2	0.3298	0.16488	2.70
2	0.4722	0.23610	3.87
2	10.2773	5.13865	84.16
2	1.3121	0.56603	9.27
8	12.2113		100

Table 19: Response Table of S/N Ratios for SR

Level	Ton	Toff	Peak Current	Servo Voltage
1	-2.5804	-0.7024	-2.3442	-0.442
2	-2.0143	-1.0217	-1.3990	-1.002
3	0.9365	-1.9340	0.0850	-2.213
Delta	3.5169	1.2315	2.4292	1.7703
Rank	1	4	2	3

Table 20: Analysis of Variance for SR

Degree of Freedom	Sum of Square	Variance	Contribution (%)
2	0.32868	0.164344	56.78
2	0.04402	0.022011	7.60
2	0.12682	0.063411	21.91
2	0.07935	0.039678	13.71
8	0.57888		100

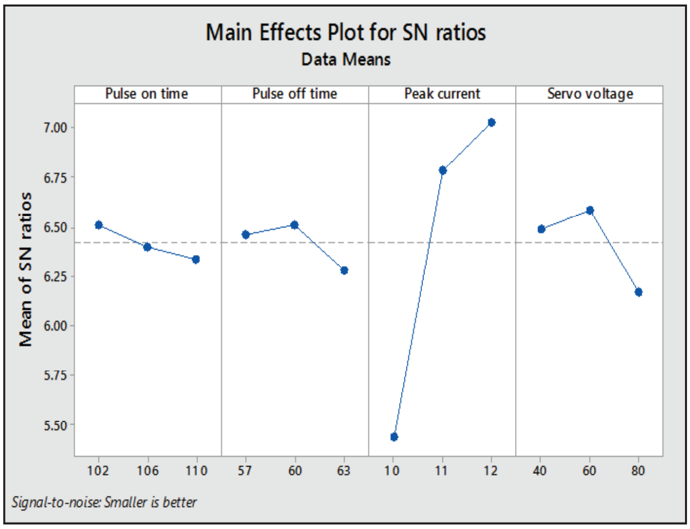

Fig. 6: Effect of Parameters on KW

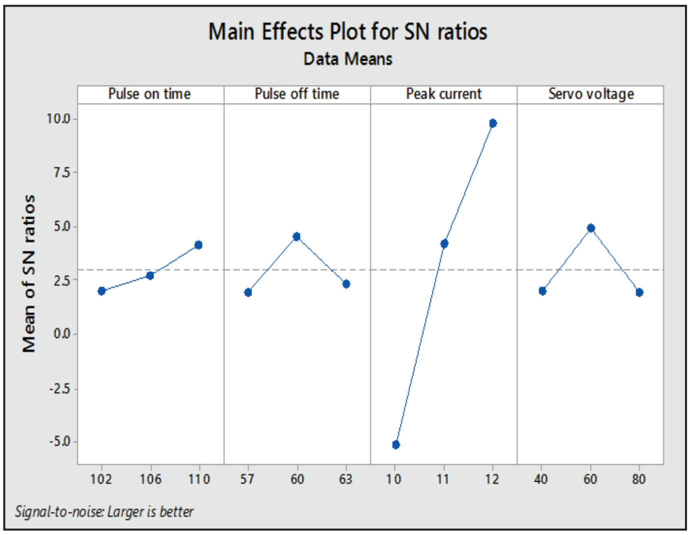

Fig. 7: Effect of Parameters on MRR

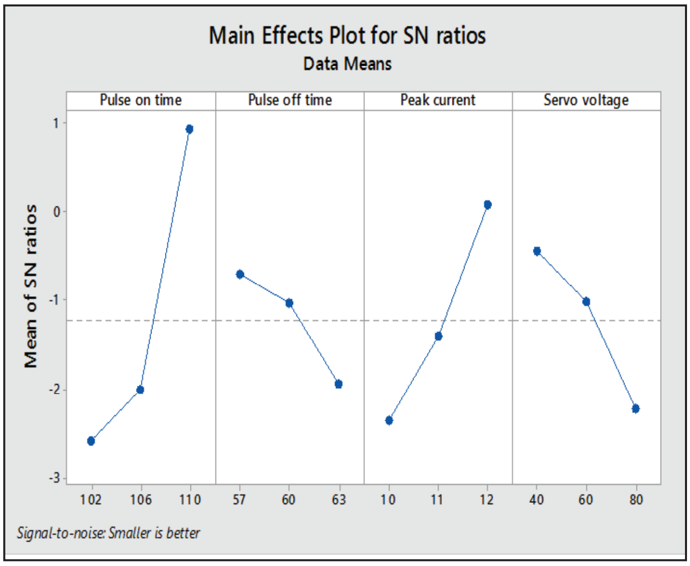

Fig. 8: Effect of parameters on SR

The aim of the experiment was to obtain the optimum factor level value which strongly affects the machining performances. From mean of S/N ratios for kerf width, it was found that peak current has the highest effect followed by servo voltage, pulse off time and pulse on time. Optimum condition for kerf width (smaller is better) was found at A1-B2-C3-D2 as shown in fig. 6. From mean of S/N ratios for MRR, It was found that peak current has highest on MRR. Optimum condition for MRR (larger is better) was found at A3-B2-C3-D2 as shown in fig. 7. From mean of S/N ratios for SR, it was found that pulse on time has the highest effect on SR. Optimum condition for SR (smaller is better) was at A3-B1-C3-D1 as shown in fig. 8.

1. Confirmation Experiment

At optimum condition experiments were performed and compared with predicted value given by Minitab 17 software for KW, MRR and SR as shown in Table 21, Table 22 and Table 23 respectively. However error can be minimized with more number of experimental run.

Table 21: Result of Confirmation Experiment for KW

	Predicated Value	Experimental Value	% error
Optimal Level	A1-B2-C3-D2	A1-B2-C3-D2	
KW (mm)	0.4268	0.4467	
S/N Ratio for KW	7.3832	6.9996	5.2

Table 22: Result of Confirmation Experiment for MRR

	Predicated Value	Experimental Value	% error
Optimal Level	A3-B2-C3-D2	A3-B2-C3-D2	
MRR(mm^3/min)	4.14403	4.5849	
S/N Ratio for MRR	14.5827	13.2265	9.3

Table 23: Result of Confirmation Experiment for SR

	Predicated Value	Experimental Value	% error
Optimal Level	A3-B1-C3-D1	A3-B1-C3-D1	
SR (µm)	0.596667	0.69	
S/N Ratio for SR	3.53474	3.22301	8.81

VI. Comparison of optimized result using brass and zinc coated brass wire

Comparison of optimum experimental value for KW, MRR and SR are shown in fig. 9 which indicates that zinc coated brass wire gives 6.53% higher KW, 19.23% higher MRR and 14.49% higher SR than brass wire.

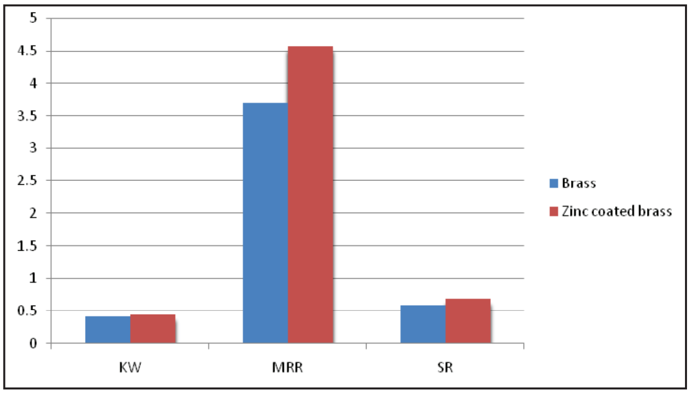

Fig. 9: Comparison of Process Performance of Brass and Zinc Coated Brass Wire

VII. Conclusion

In the present investigation Inconel 690 is machined using brass and zinc coated brass wire at same parameters for the investigation of KW, MRR and SR and following results are concluded.

- Optimal combination of parameters using brass wire are obtained at A1-B2-C3-D1, A2-B3-C2-D1 and A1-B3-C2-D1 for KW (0.4175 mm), MRR (3.7028 mm3/min) and SR (0.59 µm) respectively.
- Optimal combination of parameters using zinc coated brass wire are obtained at A1-B2-C3-D2, A3-B2-C3-D2 and A3-B1-C3-D1 for KW (0.4467 mm), MRR (4.5849 mm3/min) and SR (0.69 µm) respectively.
- Peak current is the dominating factor for almost all responses with both wires.
- Zinc coated brass wire produces 6.53% higher KW, 19.23% higher MRR and 14.49% higher SR than brass wire.

Abbrevations

MRR - material removal rate
SR - surface roughness
KW - kerf width
EDM - electric discharge machining
ANOVA - analysis of variance

References

[1] Prasad, A.V.S.R., Ramji, K., Datta, G.L. (2014).“An Experimental Study of Wire EDM on Ti-6Al-4V Alloy”, International Conference on Advances in Manufacturing and Materials Engineering, Procedia Materials Science 5, pp. 2567-2576.
[2] Shardul, S.A, Dahake, S.K.,“Parametric optimization on Graphite plate by WEDM”, International Research Journal of Engineering and Technology, Vol. 02, No. 09, 2015.
[3] Karsh,P.K., Singh, H.,“Optimization of process parameters for surface roughness of Inconel 625 in Wire EDM by using taguchi method”, ISOR Journal-JMCE, 2017, pp.58-63.
[4] Dhale, S.R., Kulkarni, M.L.,“Effect of electrode coatings in wire electrical discharge machining of inconel-718”, IOSR Journal-JMCE, Vol. 13, N0. 4, 2016, pp. 53-59.
[5] Dabade, U.A., Karidkar, S.S.,“Analysis of response variables in wedm of inconel 718 using taguchi technique”, 48th CIRP Conference on Manufacturing Systems – CIRP CMS 2015, Procedia CIRP, pp. 886 – 891.

[6] Sreenivasa, R.M., Venkaiah N.,"Modeling of Circularity error while machining inconel-690 using wedm", International Journal of Applied Engineering Research, Vol. 11, No. 6, 2016, pp. 3999-4006.

[7] Rodge, M.K., Sarpate, S.S., Sharma, S.B.,"Investigation on process response and parameters in wire edm of Inconel 625", IJMET, Vol. 4, No. 1, 2013.

[8] Rane, S.S., Prakash, C.P.S.,"Selection of optimal process parameters in machining aerospace material by wire electrical discharge machining process", International Journal for Scientific Research & Development, Vol. 3, No. 09, 2015.