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Electrical Discharge Wire Cutting Of Nimonic 75 Using Special Coated Wire

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Abstract

WEDM machines in the early 70s had an extremely low yield with cutting rates of about 21mm2/min. By early 80s, cutting rates went up to 64 mm2/min, while the current machines are able to cut at a speed more than 20 times higher than the earliest machines. The parameters that define these characteristics are wire tension, thermal load, electrical discharge impact, and flushing rate. In the early 1970s, pure copper wire electrodes were used to compromise between machining accuracy and strength. By the mid-1970s, brass wires started replacing copper wire electrodes. Following these developments, wire electrodes made of copper and coated with zinc appeared in machining applications in 1980. In the following years, brass wire electrodes coated with zinc replaced these, and brass wire electrodes were developed containing aluminum or chromium. Since 1990, brass wire electrodes have been developed with different compositions to achieve a range of processing goals. To ensure quality for high precision cutting, the brass wire electrode is coated with nano-coated brass .

Keywords: WEDM , brass , Nimonic 75

1. Introduction

The rapid growth in the development of harder and more difficult to machine metals and alloys during the last five decades [1].Conventional edged tool machining is uneconomical for such materials and the degree of accuracy and surface finish attainable is relatively poor [2]. Furthermore, the maximum surface roughness tolerable through conventional methods limits at 0.01 µm, and machining had to be carried out to an accuracy of approximately 0.1 µm. Monocrystalline diamond calling had to be used, and chips so produced were as small as or less than l µm.The production of components for microelectronics has also led to a demand for methods of machining to extremely fine and precise limits [3,4]. Wire Electrical discharge machining (WEDM) uses the same fundamental principles of material removal as EDM, but uses a traveling, small-diameter wire as the electrode. The wire travels from a supply spool, through the work piece, and on to a take-up spool [5]. In WEDM The wire travels from a supply spool, through the work piece, and on to a take-up spool. The work piece is held on a table whose movements can be directed to create the desired shape of the part. Numerical control of CNC is often used to direct table movement. Figure 1 shows a schematic of the WEDM setup .

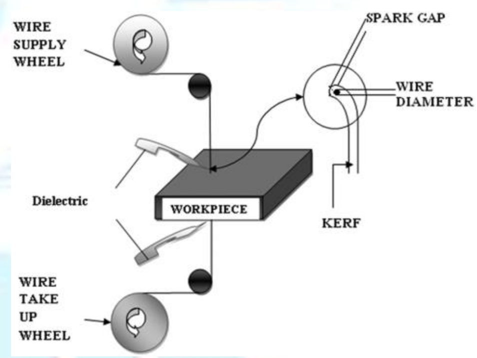

Fig. 1 A schematic of an WEDM

Nimonic 75 is a newly developed Nickel based heat resistance Super alloy with high content of Cobalt and Chromium. Processing of such type of heat resistance alloys has been an active area of research due to increase demand of this class of material and typical problems associated with the processing. Machining of heat resistance alloys is difficult due to a combination of low thermal conductivity and high temperature strength. It is very difficult to machine Nimonic 75 by conventional machining processes. Modern machine techniques such

WEDM are increasingly being used for machine such hard material [6] .

In order to improve WEDM process performance by applying a new coated wire electrode, this study embarks on two main objectives, firstly To investigate the effect of WEDM parameters on machining performance using different wire electrodes to improve surface micro-characteristics in WEDM. secondly to conclusion the performance of the new Nano-coated wire electrode. The published literature indicates that little studies have been reported for the coated wire electrode performance. There are researches studied the optimization of process parameters of wire EDM using zinc-coated brass wire . However, it has not been found that there is no available results about the performance of Nano-coated wire electrode in WEDM .So, the aim of the present investigation is to correlating the inter-relationships of various Wire electrical discharge machining (WEDM) parameters of Nimonic 75 such as feeding speed (Fs), duty factor (D), wire tension (T), wire speed (Ws) and water pressure (P) In case of using plane brass wire electrode and in case of using nano-coated wire electrode on the metal removal rate (MRR), tool wear (TW) and surface roughness (SR). This work is based on the response surface methodology (RSM) approach.
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2. Experimental Investigation

MRR, TWR and SR have been considered for evaluating the machining performance in two cases .
case 1 using plane brass electrode wire.
case 2 using nano-coated brass electrode wire .

with input machining parameters such as feeding speed (Fs), duty factor (D), wire tension (T), wire speed (Ws) and water pressure (P). The two sets of experiments were conducted on a W-B30J.SC.N.C wire electrical discharge machine.

The work pierce material used in these experiments was Nimonic 75 with dimensions of 8×8×8 mm. Figure.2 shows the schematic diagram of the WEDM process and the used experimental set up.

Two different wire electrode materials (plane brass wire and Nano -coated brass wire) were chosen to cut a very hard material (Nimonic 75) using a WEDM .Tables 1 , 2 and 3 show the Chemical composition of wires and Nimonic 75.

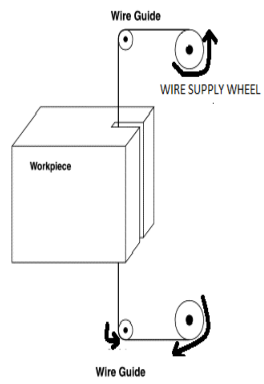

Fig. 2 Schematic of wire-EDM process

Table : 1 Chemical composition for plane Brass wire

Cu	64.0
Al	0.05
Fe	0.1
Ni	0.3
Pb	0.1
Sn	0.1
Zn	35.35

Table: 2 Chemical composition for Nano-coated brass wire

Cu	64.0
Al	0.05
Fe	0.1
Ni	0.3
Pb	0.1
Sn	0.1
Zn	35.35
External coated layer of nano- brass with thickness of 10 micron has been plated on the plane wire .	

Table: 3 Chemical composition for Nimonic 75 (wt %) .

Ni	72
Cr	20
Fe	5
Si	1
Mn	1
Ti	0.5
Cu	0.4
C	0.1

The machining time for case No.1 and case No.2 experiments was variable and related to the machining conditions and fixed parameters witch are listed in Table 4 .

Table :4 Wire EDM operating conditions for case No.1& case No.2 .

Working conditions	Description
Work piece material	Nimonic 75
Tool	(-) Polarity
Feeding speed (mm/min)	1 – 5
Pulse On-time (µs)	1-9
Pulse Off-time (µs)	9
Wire tension (gf)	1000-2000
Wire speed (m/s)	3-15
Water pressure (MPa)	1-5
Wire diameter (mm)	0.25
Peak current	Automatically selected from the machine related to the feeding speed conditions
Dielectric fluid	De-ionized water

Response surface methodology (RSM) is an interaction of mathematical and statistical techniques for modeling and optimizing the response variable models involving quantitative independent variables. The soft ware witch have been used in this study is Design-Expert 10 .

Both of case No.1 and case No.2 the range of the feeding speed (Fs), duty factor (D), wire tension (T), wire speed (Ws) and water pressure (P) settings have been selected after performing some pilot experiments. Actual and coded values of the input process parameters have been listed in Table 5. The Design of experiment matrix, showing coded and actual values of the input process parameters, is shown in Table 6.

Table : 5 Coding of process parameters for both of case No.1 and case No.2.

Input parameters	Coded value	Level				
		-2	-1	0	+1	+2
Feeding speed (Fs)	X1	1	2	3	4	5
Duty factor (D)	X2	0.1	0.2	0.3	0.4	0.5
Wire tension (T)	X3	1000	1250	1500	1750	2000
Wire speed (Ws)	X4	3	6	9	12	15
Water pressure (P)	X5	1	2	3	4	5

Table :6 Design of experiments matrix for both of case No.1 and case No.2.

Exp. No	Feeding speed mm/min	Duty factor	Wire speed m/s	Wire tension gf	Water pressure MPa
1	-1	-1	-1	-1	1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	1
7	-1	1	1	-1	1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	1
11	-1	1	-1	1	1
12	1	1	-1	1	-1
13	-1	-1	1	1	1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	1

17	-2	0	0	0	0
18	2	0	0	0	0
19	0	-2	0	0	0
20	0	2	0	0	0
21	0	0	-2	0	0
22	0	0	2	0	0
23	0	0	0	-2	0
24	0	0	0	2	0
25	0	0	0	0	-2
26	0	0	0	0	2
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0

3.Mathematical Modeling

Tables 7 , 8 show the arrangement and the results of the experiments carried out in this work, based on the central composite design. . These results are used to deduce the mathematical models, which is one of the main objectives of this work. If all variables are assumed to be measurable, the response surface can be expressed as follows:

$$y_u = f(X_1, X_2, X_3 \ldots X_k) \pm \xi \quad (3.1)$$

Where y_u is the corresponding **response** function (or response surface), X_1, X_2, $X_3 \ldots X_k$ are coded values of the machining process parameters, and ξ is the fitting error. In this study, for five variables under consideration parameters {Feeding speed (Fs), duty factor (D), wire tension (T), wire speed (Ws) and water pressure (P)**}, a second-order polynomial regression model**, which is called quadratic model, is proposed. The quadratic model of Y_u [73] can be written as follows:

$$Y_u = b_o + \sum_{i=1}^{n} b_i X_{iu} + \sum_{i=1}^{n} b_{ii} X_{iu}^2 + \sum_{j>i}^{n} b_{ij} X_{iu} X_{ju} + \varepsilon \quad (3.2)$$

- The coefficient b_o is the free term.
- The coefficients b_i are the linear terms.
- The coefficients b_{ii} are the quadratic terms.
- The coefficients b_{ii} are the interaction terms.

Table: 7 Experimental results of WEDM process for case No.1 .

Exp. No	MRR g/min	TW g/min	SR (Ra) µm
1	0.0440	0.0338	3.1
2	0.0693	0.0543	3.3
3	0.0970	0.0746	1.8
4	0.1125	0.0866	2.5
5	0.0568	0.0453	2.0
6	0.0652	0.0512	3.1
7	0.1067	0.0829	1.6
8	0.1141	0.0877	4.1
9	0.0532	0.0499	2.0
10	0.0994	0.0770	2.8
11	0.0919	0.0718	1.8
12	0.1155	0.0889	4.2
13	0.0572	0.0440	2.0
14	0.0871	0.0671	4.6
15	0.0725	0.0558	1.6
16	0.2080	0.1650	3.4
17	0.0346	0.0266	1.3
18	0.1150	0.0886	4.5
19	0.0434	0.0334	2.2
20	0.1443	0.1111	1.8
21	0.0848	0.0653	2.8
22	0.1172	0.0902	3.1
23	0.0731	0.0600	2.7
24	0.1161	0.0860	3.0
25	0.0841	0.0648	2.9
26	0.1178	0.0907	2.0
27	0.1008	0.0776	2.0
28	0.0999	0.0769	2.1
29	0.1002	0.0772	2.1
30	0.1031	0.0794	2.0
31	0.0991	0.0763	1.9
32	0.1051	0.0809	2.0

Table :8 Experimental results of WEDM process for case No.2 .

Exp. No	MRR g/min	TW g/min	SR (Ra) µm
1	0.0554	0.0275	2.4
2	0.0873	0.0442	2.5
3	0.1222	0.0607	1.4
4	0.1418	0.0705	1.9
5	0.0716	0.0369	1.3
6	0.0822	0.0417	2.4
7	0.1344	0.0675	1.2
8	0.1438	0.0714	3.1
9	0.0670	0.0442	1.5
10	0.1252	0.0627	2.2
11	0.1158	0.0584	1.4
12	0.1455	0.0724	3.2
13	0.0721	0.0359	1.5
14	0.1097	0.0546	3.5
15	0.0914	0.0454	1.2
16	0.2900	0.1360	2.6
17	0.0436	0.0217	1.0
18	0.1449	0.0721	3.5
19	0.0547	0.0272	1.7
20	0.1818	0.0904	1.4
21	0.1068	0.0575	2.2
22	0.1477	0.0735	2.4
23	0.0921	0.0488	2.1
24	0.1463	0.0700	2.3
25	0.1060	0.0527	2.2
26	0.1484	0.0738	1.5
27	0.1270	0.0632	1.5
28	0.1259	0.0626	1.6
29	0.1263	0.0628	1.6
30	0.1299	0.0646	1.5
31	0.1249	0.0621	1.5
32	0.1324	0.0659	1.5

4. Results and Discussion

The analysis has been carried out to study the effect of the input process parameters such as Feeding speed (Fs), Duty factor (D), Wire tension (T), Wire speed (Ws) and Water pressure (P) on the process responses such as metal removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) during the WEDM process in order of using the two wires (Plane Brass wire & Nano-coated Brass wire). there are Three dimensional response surface plots were formed, based on the RSM quadratic models to assess the change of response surface in each case (Case No.1 & Case No.2) . These plots can also give deep understanding of the relationship and the interaction between the process parameters and the responses . furthermore comparing the performances of the two wires (Plane Brass wire & Nano-coated Brass wire) **.**

In case No.1 Based on the RSM model, Fig. 3 shows the effect of feeding speed on MRR at various duty factors, while keeping the other parameters at centre level. Figure 3 reflects that MRR increases as the feeding speed of the wire increases. This result has been attributed to the increase of the consumed applied current which leads to the increase of the rate of the heat energy and hence the rate of melting and evaporation [69].

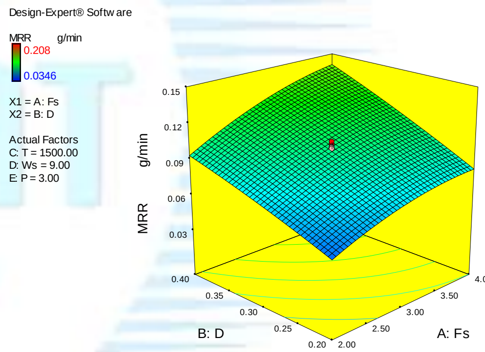

Fig. 3 Effect of feeding speed on MRR at various duty factor
T=1500gf , Ws=9 m/s , P=3 MPa

Feeding speed also increases with the increase of the duty factor. This is happen due to the fact that the increase of the duty factor means applying the same heating temperature for a longer time [7].

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In case No.1 Figures. 4 shows the effect of the feeding speed on the TW at various duty factors . Fig. 4 shows that the min. TW has been obtained at the combination of low feeding speed and low duty factor .The decrease of TW is due to the drop of the produced spark discharge energy at these conditions. Figure. 5 shows the effect of the feeding speed on the SR at various duty factors in case No.1 . Fig.5shows that the min. Ra has been obtained at the combination of low feeding speed and low duty factor .The decrease of SR is due to the drop of the produced spark discharge energy at these conditions.

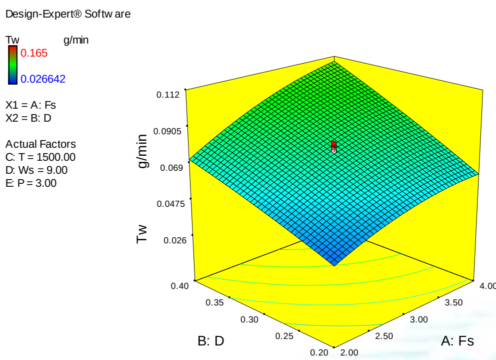

Fig. 4 Effect of the feeding speed on the TW at various duty factor
T=1500gf , Ws=9 m/s , P=3 MPa

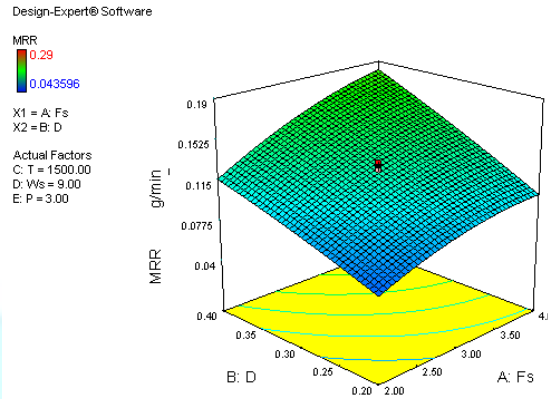

Fig.6 Effect of feeding speed on MRR at various duty factor
T=1500gf , Ws=9 m/s , P=3 MPa

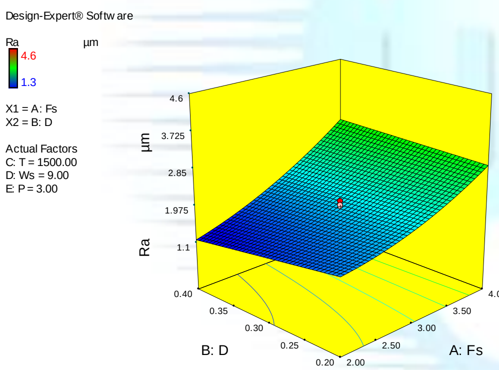

Fig. 5 Effect of the feeding speed and duty factor on the SR
T=1500gf , Ws=9 m/s , P=3 MPa

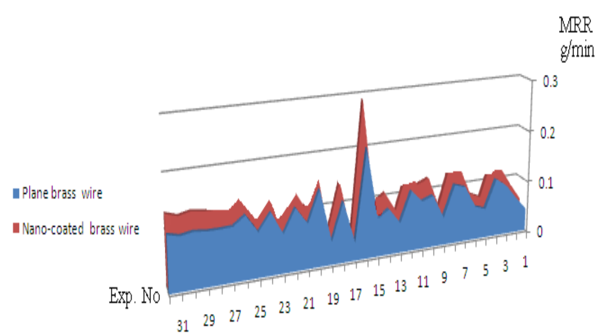

Fig. 7 shows the MRR values in the case of using Plane brass wire and in the case of using Nano-coated brass wire.

Fig. 6 shows the effect of feeding speed on MRR at various duty factors, while keeping the other parameters at centre level at case No.2.

Fig. 7 shows an increasing in almost of MRR values of case No.2 With 20% approximately when compared with the MRR Values of the case No. 1 .

Figure 8 shows the effect of the feeding speed on the TW at various duty factors at case No.2.

Fig. 9 shows a decreasing in almost of TW values With 23% approximately when compared with the TW Values of the case 1 .

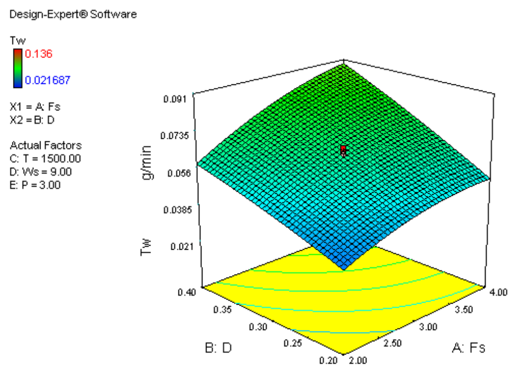

Fig.8 Effect of the feeding speed on the TW at various duty factor
T=1500gf , Ws=9 m/s , P=3 MPa

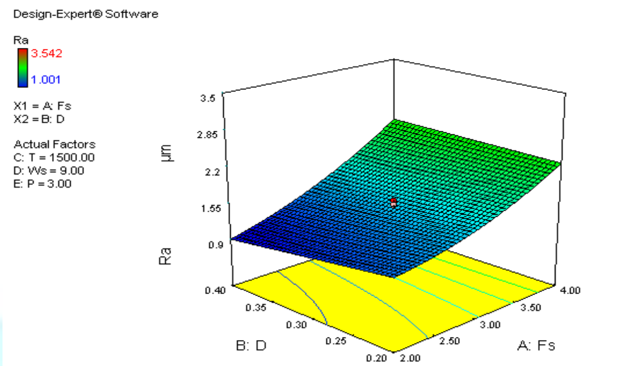

Fig. 10 Effect of the feeding speed and duty factor on the SR
T=1500gf , Ws=9 m/s , P=3 MPa

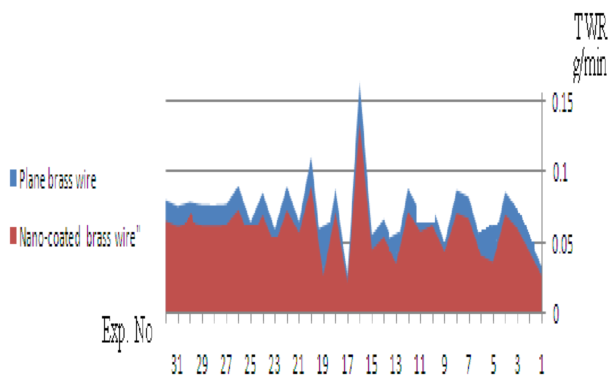

Fig . 9 shows the TW values in the case of using Plane brass wire and in the case of using Nano-coated brass wire

Fig. 10 shows the effect of the feeding speed on the SR at various duty factors at case No.2.

Fig. 11 shows a decreasing in almost of SR values With 27% approximately when compared with the SR Values of the case 1 .

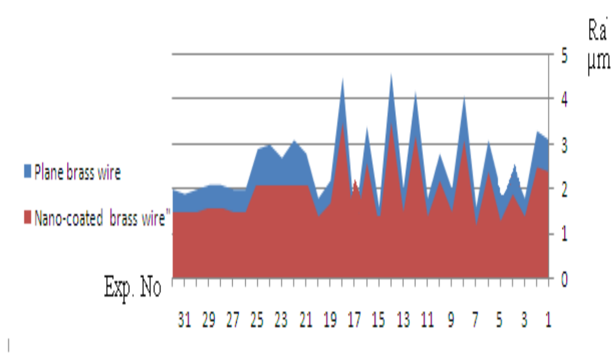

Fig. 11 shows the SR values in the case of using Plane brass wire and in the case of using Nano-coated brass wire

4. Conclusions

In this study, the influence of Nano-coated brass wire on the performance of WEDM (metal removal rate , tool wear ,and surface roughness) was compared with Plain brass wire develop an approach to perform a high performance and cost efficient WEDM wire . Also, various machining conditions were investigated to determine the effect of process parameters on the process responses (metal removal rate , tool wear ,and surface roughness) . the response surface methodology (RSM) was applied to model the results. Based on the experiments and analysis, the following conclusions can be drawn:

* The duty factor have significant effect on metal removal rate in machining Nimonic 75 with both wire types.

* feeding speed, duty factor and water pressure are effective parameters in machining of Nimonic 75 with both wire types.

* As the pulse width and feeding speed increase, surface roughness increases due to increase in the discharge energy. The larger discharge energy produces a larger crater, causing a larger surface roughness value on the work piece. Also, increase in wire tension and time between two pulses causes reduction in surface roughness.

* When time between two pulses decreases, the number of discharges increases which leads to higher surface roughness accuracy. Also, increase in wire tension results in reduced vibration which enhances surface roughness accuracy.

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