Process parameter optimization of wire EDM on weldment of Monel 400 and AISI 316 grade steel

P Hema¹ and K Aparna²
¹Department of Mechanical Engineering, Sri Venkateswara University College of Engineering, Tirupati-517502, AP, India
²Department of Production Engineering, Sri Venkateswara University College of Engineering, Tirupati-517502, AP, India.

Abstract: The purpose of this paper is to explore the optimal set of input parameters such as pulse on time, pulse off time and wire tension in Wire Electrical Discharge Machining (WEDM) on weldment of dissimilar metals of Monel 400 and AISI 316 grade steel using brass wire. This experiment describes the difference in values in material removal rate (MRR), surface roughness and kerf width with change in three process parameters. A rectangle shaped cut is made using ZNC WEDM. Each combination of parameters is considered according to the L9 Orthogonal array. Taguchi method based grey relational analysis is used and analyzed results indicated that pulse on time has a significant effect on three output parameters. 9th experiment, i.e., pulse on time at 150µs, pulse off time at 40µs, wire tension of 14 kg-f are found to be optimal process parameters.

Keywords: Wire electrical discharge machining (WEDM), Taguchi technique, material removal rate (MRR).

1. Introduction
A non-conventional method of machining that uses thermal electrical energy for machining is Wire Electrical Discharge Machining (WEDM) as it machines with good dimensional accuracy and surface finish, it is used in machining complex shapes. It is often used in the machining of hard materials that, due to vibration issues, or otherwise difficult to machine using traditional machining processes. In Wire EDM, the effect of process parameters on material removal rate (MRR), surface roughness, kerf width are to be investigated experimentally. In order to evaluate the parameters using different approaches, different methods are used. Here, as a standard for the design of experiments, Taguchi orthogonal array was used and Grey relational analysis was carried out. In this study, the cutting factors considered are pulse on time, pulse off time and wire tension. Using Pulsed Current Gas Tungsten Arc welding using three different filler metals such as ER309L, ERNiCu-7 and ERNiCrFe-3, K.Devendranath Ramkumar, N.Arivazhagan (2014) investigated the pulsed current for joining two different Monel400 and AISI304 metals using Pulsed Current Gas Tungsten Arc welding and obtained that parent metal Monel 400 had better tensile properties compared to other areas. Angolkar Pooja, J Saikrishna (2017) have investigated the weldability of steel grade Monel 400 and AISI 316 and mechanical properties such as tensile strength, hardness are measured. Residual stresses are measured and maximum stress tensors at the welded joint are defined. J. Jeeamalar, Dr. S. Ramabalan (2017) found that both optimization and prediction can be used by taguchi experimental design tool. Rajyalakshmi.G (2013) analyzed the optimization of process parameters of Wire Electrical Discharge...
Machining performed on Inconel 825 alloy. The major performance Characteristics selected to evaluate the process are material removal rate(MRR), surface roughness (SR), and spark gap (SG) using grey relational analysis by using multi objective optimization. Applying grey relational analysis to a problem with multiple-performance characteristics is proven to be capable of objectively reflecting the relative importance of each performance characteristics. Most of the researchers have focussed on parameter optimization of wire EDM on single metal so, experimental investigation was done on a welded zone of dissimilar metals. In the present study weldment of Monel 400 and AISI 316 stainless steel is used as work piece material welded by arc welding joined by butt joint and 0.25mm² brass wire is used for machining. Experiments were designed and conducted based on Taguchi’s L9 orthogonal array and Grey relational analysis is performed to obtain multi objective optimization of required parameters such as Material removal rate (MRR), surface roughness, and kerf width by varying the process parameters like pulse on time, pulse off time and wire tension.

2. Experimental setup and methodology

The metals and the filler metal employed in this study were Monel 400, AISI 316 and E7018 electrode respectively. Metals were sliced to the dimensions of 120 mm x 40 mm x 8 mm. These samples were clamped firmly in the fixture designed with a copper back plate so as to avoid distortions and bending during welding. The process parameters were established from the open literatures as well as from the trial and error studies. Followed by welding, the weldments were cut into different coupons using wire cut EDM (Electrical Discharge Machining).

2.1 Machine setup before machining

The experiments were carried on the RATNAPARKHI WEDM machine. The wire was made vertical on verticality block and the work piece is mounted and clamped to the work table. A reference point was set for setting work coordinate system. The programming was done with reference to the WCS. The reference point was defined by the ground edges of work piece. The program was made for cutting operation and a profile of 26.5mm x16.5mm obtained dividing the total dimensions of work piece into equal rectangular blocks. While, performing various experiments precautionary measures were taken to reduce error.

3. Experiment procedure on wire EDM

Work piece after welding is clamped in the WEDM. The work piece is divided into L9 orthogonal array with each rectangular block of dimension 13.5X26.5X8mm. Then each rectangular block is cut by changing different input parameters according to L9 orthogonal array where 9 experiments were performed by varying the input parameters. Three input parameters were considered at three levels pulse on time at 130µs, 140µs, 150µs, pulse off time at 20µs, 30µs, 40µs and wire tension at 13kg-f, 14kg-f, 15kg-f are arranged according to L9 orthogonal array. Machining time for each rectangular array is measured. After cutting all the rectangular blocks the surface roughness of each side of rectangular block is measured using taly surf method and the average value is taken. Width of each rectangular block is measured using digital micrometer and difference between obtained dimension and calculated dimension were measured and noted as kerf width. Through rectangular holes are machined using WEDM set-up are shown in the below figure (1) by varying process parameters like pulse on time, pulse off time, wire tension with a dielectric fluid, then the corresponding response readings is recorded in the designed experiment tables as shown in below table (1) and the rectangular blocks cut were labelled in the figure (1) below. The Metal Removal Rate (MRR) is calculated based on ratio of difference in work piece weight to the product of density and machining time of material. Similarly surface roughness is measured by taly surf instrument and kerf
**3.1 Calculation of process parameters**

\[
\text{MRR} = \frac{(W_{jb} - W_{ja})}{\rho t} \text{mm}^3/\text{min}
\]  

Whereas,

\[ W_{jb} = \text{Initial weight of work piece before machining in gm} \]

\[ W_{ja} = \text{Final weight of work piece after machining in gm} \]

\[ t = \text{Machining time in minutes.} \]

\[ \rho = \text{Density of material in gm/mm}^3 \]

MRR is calculated by weighing the work piece before machining and after machining and the difference is calculated by dividing with product of machining time and density.

The surface roughness parameter used to evaluate surface roughness is the Roughness average (Ra). This parameter is also known as the arithmetic mean roughness value, the arithmetic average or centerline average. The average roughness is the area between the roughness profile and its Centre line is measured using Taly surf instrument. After machining the blocks surface roughness of each rectangular block is measured.

Kerf width is measured in millimetres (mm). It is the measure of the amount of the material that is wasted during machining and determines the dimensional accuracy of the finishing part. Kerf width is measured using digital vernier calliper by taking the difference in width assumed and width obtained.

**Table 1. Experimental Results**

| Experiment no | Pulse on time (µs) | Pulse off time (µs) | Wire tension (kg-f) | MRR (mm³/sec) | Surface roughness (µm) | Kerf width (mm) |
|---------------|--------------------|---------------------|---------------------|---------------|------------------------|-----------------|
| 1             | 130                | 20                  | 13                  | 16.123        | 1.90                   | 0.699           |
| 2             | 130                | 30                  | 14                  | 16.20         | 1.93                   | 0.645           |
| 3             | 130                | 40                  | 15                  | 15.53         | 1.964                  | 0.6134          |
| 4             | 140                | 20                  | 14                  | 18.76         | 2.43                   | 0.523           |
| 5             | 140                | 30                  | 15                  | 17.94         | 2.52                   | 0.549           |
| 6             | 140                | 40                  | 13                  | 17.52         | 2.61                   | 0.432           |
| 7             | 150                | 20                  | 15                  | 20.4          | 2.81                   | 0.399           |
| 8             | 150                | 30                  | 13                  | 19.23         | 2.94                   | 0.383           |
| 9             | 150                | 40                  | 14                  | 18.84         | 3.01                   | 0.225           |
4. Results and discussions

MRR values which are tabulated are analyzed in MINITAB19 software and SN ratios and graphs were obtained for finding the most effective parameter during machining.

![SN ratio graph for MRR](image)

**Figure 2. SN ratio graph for MRR**

The S/N ratio plot for MRR in the above figure (2) has shown the significance of each parameter. It is clear from S/N ratio plots that these plots were generated based on “Larger is Better” 130µs is the effective parameter for pulse on time and pulse off time at 40µs is the effective parameter and wire tension at 13kg-f is the effective parameter as the mean of SN ratios at these parameters have lesser noise.

Surface roughness values which are tabulated are analyzed in MINITAB19 software and SN ratios and graphs were obtained for finding the most effective parameter during machining. These plots were generated based on “Smaller is better”.

![SN ratio graph for surface roughness](image)

**Figure 3. SN ratio graph for surface roughness**

The SN ratio graph for surface roughness in above figure (3) has shown that pulse on time has less noise at 130µs pulse off time is more effective at 20µs and wire tension is more effective at 14 kg-f.
Figure 4 SN ratio graph for kerf width

The S/N ratios plot for kerf width shown in the above figure (4) has shown the significance of each parameter. These plots were generated based on “Smaller is better”. Pulse on time at 130µs is the most effective parameter and pulse off time at 20µs and wire tension at 15kg-f is the most effective parameter. The S/N ratio plots indicated and predicted the optimal parameters for a single variable.

Empirical modelling of the three output parameters were done by taking 3 process parameters as input variables Regression equations are formulated for the three output parameters and R-sq values are found for three output parameters.

MRR = -7.56 + 0.1770 Pulse on time - 0.0566 Pulse off time + 0.166 wire tension. (2)

R-sq values for MRR is 97.45%

Surface roughness = -4.637 + 0.05068 Pulse on time + 0.00608 Pulse off time-0.0125 wire tension. (3)

R-sq values for surface roughness is 99.03%

Kerf width = 2.779 - 0.01584 Pulse on time - 0.00584 Pulse off time+ 0.0079 wire tension. (4)

R-sq values for kerf width is 94.99%.

Grey relational analysis is performed for multi objective optimization of parameters from the grey relational grade rankings are given to the parameters.SN ratios, normalized SN ratios, grey relational coefficients, grey relational grades are found in order. G.Rajyalakshmi (2013).
Table 2. Grey relational grade and rank tabulation

| Exp no | Pulse on time(µs) | Pulse off time(µs) | Wire tension (kg-f) | MRR(mm³/min) | Surface Roughness (µm) | Kerf width (mm) | Grey relational grade | Rank |
|--------|------------------|--------------------|---------------------|--------------|------------------------|----------------|-----------------------|------|
| 1      | 130              | 20                 | 13                  | 16.123       | 1.90                   | 0.699          | 0.5653                | 3    |
| 2      | 130              | 30                 | 14                  | 16.20        | 1.934                  | 0.645          | 0.5566                | 4    |
| 3      | 130              | 40                 | 15                  | 15.53        | 1.965                  | 0.6134         | 0.5317                | 6    |
| 4      | 140              | 20                 | 14                  | 18.76        | 2.43                   | 0.523          | 0.5173                | 7    |
| 5      | 140              | 30                 | 15                  | 17.94        | 2.52                   | 0.549          | 0.4640                | 9    |
| 6      | 140              | 40                 | 13                  | 17.52        | 2.61                   | 0.432          | 0.4768                | 8    |
| 7      | 150              | 20                 | 15                  | 20.4         | 2.89                   | 0.399          | 0.6745                | 2    |
| 8      | 150              | 30                 | 13                  | 19.23        | 2.94                   | 0.383          | 0.5411                | 5    |
| 9      | 150              | 40                 | 14                  | 18.84        | 3.01                   | 0.225          | 0.6476                | 1    |

The above tabular column (2) shows the tabulation of grey relational grade and ranking of the experiments based on the desired output, i.e. high material removal rate, low surface roughness and lower kerf width.

5. Conclusions
An indigenous set-up of wire Electrical Discharge Machine is utilized to bring-out machining of through holes on weldment of Monel 400 and AISI 316 grade steel work pieces. These are the below conclusions from present work. Through holes are machined on work piece of thickness 8 mm and electrode wire 0.25mm² of size with de-ionized water as dielectric medium by varying the control parameters like pulse on time, pulse off time, wire tension. The effects of process parameters on performance parameters like Machining time, MRR and surface roughness and kerf width are discussed in detail and the constituent results are obtained.

- The optimal parameters obtained by observing the SN ratio graphs are A₁B₃C₁ for material removal rate i.e., pulse on time at 150 µs, pulse off time at 20 µs, and wire tension at 14kg-f has high material removal rate.
- The optimal parameters obtained by observing the graphs are A₁B₁C₁ for surface roughness i.e., pulse on time at 150µs, pulse off time at 40µs and wire tension at 13kg-f has lower surface roughness.
- The optimal parameters obtained by observing the graphs are A₁B₁C₃ for kerf width i.e., pulse on time at 130µs, pulse off time at 20µs, and wire tension at 15kg-f has lower kerf width.
- On performing the Regression analysis it has been found that surface roughness is the most effected parameter as it contains highest R-Sq value i.e., 99.03%.
- Grey analysis was performed and optimal parameters for all the three process parameters were found at pulse on time at 150µs, pulse off time at 40µs and wire tension at 14kg-f i.e., at these input parameters high material rate and lower surface roughness and kerf width are
obtained. Machining of weldment at the welded joint has become difficult and wire breakage has happened and experiments are performed by varying different parameters but wire burn and breakage has happened at the joint.

The following are the major reasons

- Due to bad welding and welding defects.
- Angular distortion during welding.
- Insufficient parameter ranges of WEDM machine.
- Non conductive behavior of impurities at the weld joint.

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