Multi-Optimization of Process parameters for Inconel 718While Die-Sink EDM Using Multi-Criterion Decision Making Methods

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Abstract. The objective of the paper is to apply Multi-criterion Decision Making methods in manufacturing specially in machining using EDM and to obtain an optimal setting of process parameters resulting in an optimal value of the material removal rate and tool wear rate while EDM for Inconel 718 using copper cadmium as electrode. Taguchi L9 array has been used to design the experiments, the results are further analyzed using Multi-criterion Decision Making techniques named Technique for order preference by similarity to ideal solution (TOPSIS) and Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) to investigate the multi-optimization of response characteristics for Inconel 718.

1. Introduction
Alloys based upon Inconel are widely used in many areas like medical, aviation, nuclear fusion and fission as these are having unmatched mechanical properties like fatigue resistance, corrosion and creep at elevated/high temperature[1][2]. Roughly half of the material used in aviation industries is Inconel alloys. Out of all Inconel based alloys Inconel 718 is used for manufacturing the component of prime movers like turbine, fines and engine part of turbines etc.[3]. While machining these material high temperature causes problems because of lower thermal conductivity [4] [5, 6]. The hard abrasive particles and carbides that got embedded in Inconel alloys lead to increased tool wear of cutting tools, which in turn negatively affect the topography of work-piece [7].

Among Nickel based super alloys, Inconel 718 is one of the most challenging material while machining as it retains its hardness at high to moderate temperature so making it a good choice to work in that situations. As the material is used in aviation industries so shape requirement for these industries cannot be fabricated by conventional methods of machining beside the shape surface quality requirement cannot be fulfilled using conventional machine tools. Moreover Inconel 718 is pertaining very poor thermal conductivity and rapid work hardening rate worse the machine-ability with traditional way of manufacturing. Usually, a nonconventional machining method like electrical discharge machining (EDM) is chosen for machining Inconel 718 in order to machine it. As it is having very good physical properties at high temperature, this material is addressed by many researchers now days as it is in great demand by engines structure, major challenge during machining of this material is rate at which material is being removed using non conventional methods. For last 10-15 years because of lucrative advantages EDM became a central manufacturing process. It has proved its adequacy for cutting material which are hard but electrically conductive as those used in aviation.
industries and were creating problems while machining with conventional way of machining. As far as tool materials are concerned, Cu being a good electrical as well as thermal conductor became good choice even for strength material which are Cu alloys like Cu cadmium serves purpose of tooling in case of die sink EDM. So Electrical discharge machining (EDM) is an great choice for machining Inconel alloys due to its mechanisms in which tool don’t in direct touch with work piece so make it suitable for machining [9, 10]. The process of EDM is capable of creating burr-free micro structures with very high L/D ratio, aspect ratios. Therefore, EDM is having fitness for producing various constituents made of materials with high strength, hardness and toughness [11]. Bharti et al. [9] explained the machining attributes of die-sinking EDM on Inconel 718 with Cu as tool material. Author found that the discharge current is the most influential input parameter on each output measure. Discharge current and pulse-on-time are identified as common influencing parameters for material removal rate, surface roughness and tool wear rate. In majorly, researchers in literature on EDM-machined surface integrity are restricted to investigating tool Steel. Very less research [11,12] has been conducted regarding EDMed surface characteristics for Inconel alloys to investigate relationship between input parameters in wedge and surface recast layer after machining.

2. Experimental Details

In present investigations, Nickel base super alloys, Inconel 718 were used as the material for the work piece (specimens 14mm diameter) and Cu-cadmium as a tool electrode/material. The experiments were carried out on a standard CNC EDM machine, ZNC 50A Sparkonix, Pune with straight polarity. For flushing and cooling purpose, EDM oil with specific gravity of 0.7 was used as dielectric medium. The EDM experimental conditions and parameters are encapsulated in Table 1. To measure material that is being removed and electrode wear rate is captured using a weighting machine that was having a least count of 0.1 mg, work-piece and tool was weighted before and after of each trial, time taken for each trial was kept as 10 minutes.

| Experimental Parameters | Parameters | Level |
|-------------------------|------------|-------|
| Work-piece              | Inconel 718 |
| Tool Electrode          | copper Cadmium |
| Peak Current (A)        | 5,6,7      |
| Pulse-Duration (µs)     | 150,175,200 |
| Pulse-interval(µs)      | 5,6,7      |
| Gap-Voltage(V)          | 50,52,54   |
| Polarity                | Positive   |
| Dielectric Fluid        | EDM Oil    |
| Machining Time(min)     | 10         |

In this work identification of input factors and their levels are mentioned in Table 1. The factor selection were made on the behalf of literature survey and levels are decided with the help of pilot test as well as literature survey done so far. Experiments were carried according to L9 array that has been decided after reaching number of factors and levels of each factor.
Traditional methods are complex and number of experiments needed for the same are very large in number as soon as the number of factors and levels increased and these studies are considered for off line quality control. A Taguchi design is having orthogonal array which are having orthogonality, a method of designing experiments in which we need to perform only selected no of experiments out of the full possible combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

Table 2 L9 Array for Experiments

| Experiment No. | Peak Current ($I_p$) | Pulse On Time ($T_{on}$) | Pulse Off Time ($T_{off}$) | Gap Voltage (V) |
|----------------|----------------------|--------------------------|--------------------------|-----------------|
| 1              | 5                    | 150                      | 5                        | 50              |
| 2              | 5                    | 175                      | 6                        | 52              |
| 3              | 5                    | 200                      | 7                        | 54              |
| 4              | 6                    | 150                      | 6                        | 54              |
| 5              | 6                    | 175                      | 7                        | 50              |
| 6              | 6                    | 200                      | 5                        | 52              |
| 7              | 7                    | 150                      | 7                        | 52              |
| 8              | 7                    | 175                      | 5                        | 54              |
| 9              | 7                    | 200                      | 6                        | 50              |

2.1 Results

After conducting experiments as per Taguchi L9 array we got following results as material removal rate and electrode wear rate, values of below given tables are from a weighting machining which is having a least count of 0.1 mg. Machining time is kept 10 min for all experiments.

Table 3 Experimental Results for MRR & TWR

| Experiment No. | MRR (gm/min) | TWR (gm/min) |
|----------------|--------------|--------------|
| 1              | 0.024579     | 0.000865     |
| 2              | 0.026123     | 0.000846     |
| 3              | 0.03325      | 0.000005     |
| 4              | 0.04081      | 0.00012      |
| 5              | 0.06012      | 0.00005      |
| 6              | 0.04099      | 0.00011      |
| 7              | **0.07177**  | 0.00018      |
| 8              | 0.05999      | 0.00004      |
| 9              | 0.062774     | **0.000017** |

3. Optimization

3.1. TOPSIS

The multi-criterion decision making methods are very much popular in the field of manufacturing sector for the prediction of optimum parameters selection. TOPSIS is one of the MCDM techniques, in
this particular method we strive for best alternative which is at minimum distance from ideal solution and at maximum from worst solution. Procedure for TOPSIS method is having following steps [5].

Step 1. In first step objective and attributes are decided. For instance in our problem MRR is a beneficial criterion and the surface roughness is non beneficial attribute. For MRR we need higher value and for roughness we need it to minimize.

Step 2. All the data available is represented in a decision matrix. In our case we have conducted 9 experiments and two response factors are present, so matrix will be of size 9x2 form.

\[
M_{9 \times 2} = \begin{bmatrix}
0.02457 & 0.000865 \\
0.02612 & 0.000846 \\
0.03325 & 0.000005 \\
0.04081 & 0.00012 \\
0.06012 & 0.000005 \\
0.04099 & 0.00011 \\
0.07177 & 0.00018 \\
0.05999 & 0.00004 \\
0.06277 & 0.00001
\end{bmatrix}
\]

Step 3. In next step normalized matrix is obtained \(N_{9 \times 2}\) using the formula

\[
Ni \times j = \frac{Xij}{\sqrt{\sum X 2ij}}
\]

Step 4. Normalised matrix obtained from above step is further multiplied with weights that are decided normally by the persons who are specialist in that area. For our case we have given weight to MRR as 0.6 and 0.4 to TWR attributes i.e. 60% weight is given to MRR and 40% to TWR. From this step we got weighted normalised matrix.

\[
Vij = \begin{bmatrix}
0.099331143 & 0.279749106 \\
0.105570912 & 0.273604328 \\
0.134373266 & 0.016170469 \\
0.164925504 & 0.038809124 \\
0.242963031 & 0.016170469 \\
0.165652938 & 0.035575031 \\
0.29004419 & 0.058213687 \\
0.242437661 & 0.012936375 \\
0.253688644 & 0.005497959
\end{bmatrix}
\]

Step 5 from the weighted matrix we find the positive ideal and negative ideal solution these are calculated.

Step 6. From ideal positive and negative values, separation is calculated for each alternatives, in our case we have nine alternatives so we will have 18 separation value for every alternate from positive and worst values.

Step 7 Lastly we have to calculate the relative closeness is calculated from ideal solution as given below way
5

\[
Ci = \frac{Si1}{Si1 + Si2}
\]

Where \( C_i \) is the closeness of the alternate to ideal solution
\( Si1 \) is the separation from ideal negative solution
\( Si2 \) is the separation from ideal positive solution

Table 4 Separation measures from ideal best and worst solution

| Sr. No. | Separation from Ideal Best | Separation from Ideal Worst | Relative Closeness | Rank of Alternate |
|---------|----------------------------|----------------------------|--------------------|------------------|
| 1       | 0.30545                    | 0.22162                    | 0.42048            | 5                |
| 2       | 0.29700                    | 0.21539                    | 0.42036            | 6                |
| 3       | 0.11932                    | 0.05096                    | 0.29929            | 9                |
| 4       | 0.09160                    | 0.06245                    | 0.40536            | 8                |
| 5       | 0.01073                    | 0.14368                    | 0.93054            | 2                |
| 6       | 0.09015                    | 0.06421                    | 0.41596            | 7                |
| 7       | 0.05558                    | 0.18447                    | 0.76846            | 4                |
| 8       | 0.01171                    | 0.14416                    | 0.92489            | 3                |
| 9       | 0.01067                    | 0.15722                    | \textbf{0.93643}   | 1                |

3.2 PROMETHEE

It stands for Preference Ranking Organisation Method for Enrichment Evaluations. The ELECTRE and the PROMETHEE are the two most commonly used methods out of groups of the outranking methods introduced by Roy (1973). PROMETHEE is a multi criterion decision making method given or formulated by Brans and Vinke (1985 [6]. In literature this technique is used in every orbit of science and technology [7] But only few or limited no of papers finds application in manufacturing such as, scheduling[8] . In case of production and manufacturing these techniques with AHP method can be applied successfully, it can be very helpful in the manufacturing while selecting the input parameters for cutting .In this method following steps are adopted to address the problem of multi optimisation.

Step 1. In first step we started from our problem, we have two criterion and nine alternatives, none of the alternatives fits for the best solution for all criterion as shown in table no.3

Step 2. After short-listing the alternatives, decision table including the data values of all criteria for the short-listed alternatives is formulated . The weights for individual importance for each criteria can also be labelled using analytic hierarchy process (AHP) method[10]. Otherwise if operator or concerned person is sure about weight can assign weight of the attribute. In this study equal weight is given to MRR and surface roughness that is 0.5.

Step 3. In this step we calculate preference function, when we compare the contribution of the each available option (alternatives) in form of a function. The preference function \( F_{i1t2} \) translates the difference between the evaluations obtained by two alternatives \( (c_1 \) and \( c_2 \)) in terms of a particular criterion, into a preference degree ranging from 0 to 1. Let \( F_{i1t2} \) be the preference function associated to the criterion \( C_i \).

\[
F_{i1t2} = Gi\left[c_i(t1) - c_i(t2)\right]
\]

where \( F_{i1t2} \) lies between 0 and 1
Where $G_i$ is the function of deviation from between alternative for a particular criterion.

Table 5 Preference value for alternative when Pair-wise compared for MRR

|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 1 | 1 | 1 | -- | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | -- | 1 | 0 | 1 | 0 |
| 6 | 1 | 1 | 1 | 1 | 0 | -- | 0 | 0 | 0 |
| 7 | 1 | 1 | 1 | 1 | 1 | -- | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | -- | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | -- |

Table 6 Preference value for alternative when Pair-wise compared for TWR

|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | -- | 1 | -- | 1 | 1 | 0 | 0 |
| 4 | 1 | 1 | 0 | -- | 0 | 0 | 1 | 0 | 0 |
| 5 | 1 | 1 | -- | 1 | -- | 1 | 1 | 0 | 0 |
| 6 | 1 | 1 | 0 | 1 | 0 | -- | 1 | 0 | 0 |
| 7 | 1 | 1 | 0 | 0 | 0 | 0 | -- | 0 | 0 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | -- | 0 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | -- |

Steps 4 In third step we calculate the CPI that is criterion preference index that is calculated as follow

$$CPI_{t1t2} = \sum_{1}^{2} w_i F_{t1t2}$$  \hspace{1cm} (3)

Where $W_i$ is the weight given for each criterion i.e. 0.5 for each in this case.

Summation is carried out for each criterion that is two in this case.

Table 7 CPI Matrix

|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | $\Phi^+$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | -- | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 3 | 1 | 1 | -- | 0.4 | 0 | 0.4 | 0 | 0.4 | 0 | 3.2 |
| 4 | 1 | 1 | 1 | -- | 0 | 0 | 0.4 | 0 | 0.4 | 3 |
| 5 | 1 | 1 | 1 | 0.6 | -- | 1 | 0.4 | 0.6 | 0 | 5.2 |
| 6 | 1 | 1 | 1 | 1 | 0 | -- | 0.4 | 0 | 0.4 | 4 |
| 7 | 1 | 1 | 1 | 0.6 | 0.6 | 0.6 | -- | 0.6 | 0.6 | 5.6 |
| 8 | 1 | 1 | 1 | 1 | 0.4 | 1 | 0.4 | -- | 0 | 5.8 |
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.4 | 1 | -- | 7.4 |
Step 4. At last we calculate the For PROMETHEE outranking relations, the outgoing flux, entering flow and the net flow/flux for an alternative a belonging to a set of nine alternatives. $\Psi(t_i)$ is called the leaving flow, $\Psi(t_j)$ is called the entering flow and $\Psi(t)$ is called the net flow/flux.

| EXPERIMENT NUMBER | $\phi^+ - \phi^-$ |
|-------------------|-------------------|
| 1                 | -8                |
| 2                 | -6                |
| 3                 | -1.2              |
| 4                 | -1.6              |
| 5                 | 1                 |
| 6                 | 1.2               |
| 7                 | 1.6               |
| 8                 | 3.6               |
| 9                 | 6.8               |

### 4. CONCLUSION

This paper discussed the applicability of Multi-criterion Decision Methods in the field of manufacturing environment. In this study multi-optimisation problem is addressed by two well known methods namely TOPSIS and PROMETHEE while studying opposite in nature criterion MRR and TWR for a material Inconel 718 while EDM machining. But with these methods we can apply set of advised input parameters to machine Inconel 718 using Die-sink EDM that can lead save time as well cost.

- TOPSIS and PROMETHEE methods successfully applied to address problem in the field of manufacturing environment.
- Alternate are sorted by using both methods, TOPSIS sorted the alternate in the rank of closeness with optimum solution as 9th best and 3rd as worst. Where as PROMETHEE ranked the alternates as 9th best and 1st worst.
- For the weight considered in study, optimal parameters values Current as 7 amperes, Gap voltage as 50 volts, Pulse on and Pulse off as 200 and 6 micro seconds respectively.
- It is evident from above suggested values that alternative 9 should be first choice for assumed/given weight age for alternatives.
- These methods don’t use much computation so it can be used as very simple and effective tools for addressing optimisation problems.

### References

[1] F. Wang, Y. Liu, Y. Shen, R. Ji, Z. Tang, and Y. Zhang, “Machining performance of inconel 718 using high current density electrical discharge milling,” *Mater. Manuf. Process.*, vol. 28, no. 10, pp. 1147–1152, 2013.

[2] H. L. Lin and T. M. Wu, “Effects of activating flux on weld bead geometry of inconel 718 alloy TIG welds,” *Mater. Manuf. Process.*, vol. 27, no. 12, pp. 1457–1461, 2012.
[3] D. G. Thakur, B. Ramamoorthy, and L. Vijayaraghavan, “A Study on the Parameters in High-Speed Turning of Superalloy Inconel 718,” Mater. Manuf. Process., vol. 24, no. 4, pp. 497–503, Feb. 2009.

[4] Z.-P. Hao, Y. Lu, D. Gao, Y.-H. Fan, and Y.-L. Chang, “Cutting Parameter Optimization Based on Optimal Cutting Temperature in Machining Inconel718,” Mater. Manuf. Process., vol. 27, no. 10, pp. 1084–1089, Oct. 2012.

[5] R. V. Rao, “Machinability evaluation of work materials using a combined multiple attribute decision-making method,” Int. J. Adv. Manuf. Technol., vol. 28, no. 3–4, pp. 221–227, 2006.

[6] G. Anand and R. Kodali, “Selection of lean manufacturing systems using the PROMETHEE,” J. Model. Manag., vol. 3, no. 1, pp. 40–70, 2008.

[7] M. Behzadian, R. B. Kazemzadeh, A. Albadvi, and M. Aghdasi, “PROMETHEE: A comprehensive literature review on methodologies and applications,” Eur. J. Oper. Res., vol. 200, no. 1, pp. 198–215, 2010.

[8] O. U. Araz, “A simulation based multi-criteria scheduling approach of dual-resource constrained manufacturing systems with neural networks,” Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 3809 LNAI, pp. 1047–1052, 2005.

[9] R. V. Rao and B. K. Patel, “Decision making in the manufacturing environment using an improved PROMETHEE method,” Int. J. Prod. Res., vol. 48, no. 16, pp. 4665–4682, 2010.

[10] T. L. Saaty, “Decision making with the analytic hierarchy process,” Int. J. Serv. Sci., vol. 1, no. 1, p. 83, 2008.

[11] Newton, T.R.; Melkote, S.N.; Watkins, T.R.; Trejo, R.M.; Reister, L. Investigation of the effect of process parameters on the formation and characteristics of recast layer in wire-EDM of inconel 718. Materials Science and Engineering A 2009, 513-514 (C), 208–215.

[12] Aspinwall, D.K.; Soo, S.L.; Berrisford, A.E.; Walder, G. Workpiece surface roughness and integrity after WEDM of Ti-6Al-4V and Inconel 718 using minimum damage generator technology. CIRP Annals-Manufacturing Technology 2008, 57 (1), 187–190.