Influence of Powder Mixed EDM on the Surface Hardness of Die steel

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Abstract. Improving the surface hardness of molds after EDM is still being challenged by many researchers. In this research, an effort was made to enhance the surface hardness of die steel though adding metal powder to dielectric and optimization parameters of EDM. Process factors are workpiece types, concentrations, powder types, and electrical variables of the machine. Taguchi’s method has been used to design experiment and the results have been analyzed by ANOVA. The influence of the factors on micro hardness was evaluated through the mean and signal to noise ratio(S/N) of micro hardness. The results showed that, the mixing of Mn powder with insulator fluid results in high micro-hardness compared with aluminum powder, mixed powder of aluminum and manganese, also with pure dielectric. The significant factors for micro-hardness is a powder type (Mn) and has more contribution 43%. The factors of pulse on time and concentration have no significant effect on hardness of mold surface.

1. Introduction

Electrical discharge machining (EDM) is a non-conventional process, it has been used to manufacture die and mold. EDM is widely used to manufacture intricate parts with high dimensional and accuracy. The mold surface integrity is one of the most important issues, surface integrity is represented by some of the characteristics like the high surface hardness, lack of pores, low roughness, and surface cracks. Such a surface is demanded by manufacturers, because the molds surface exposed to abrasion and chemical effects, these effects reduce the life of the mold. The mold surface life and performance would be influenced by the surface characteristics that results after the EDM process, like the hardness of the surface, corrosion resistance and wear resistance. The surface characteristics like hardness, wear resistance, and corrosion resistance could be improved by adding metal powders like (Al, Ni, Cr) to a dielectric of EDM this lead to increase these characteristics [1].

The use of powder mixed EDM is a way to improve the surface hardness and in turn increase the molds life through the increase abrasion resistance [2].

Die steels are among expensive materials used in manufacturing molds, these materials are difficult to cut it because it characterized with hardness properties. Such materials cannot be machined by conventional machining processes like turning and milling processes. Therefore, nonconventional processes are normally used in machining these types of materials. PMEDM is one of the most important processes is used in this aspect [3, 5].

Pecas and Henriques [4] reported that powder mixed EDM is a developing method, which has given a new manner to enhance the process abilities and produce low surface roughness with reduce surface microcracks and thin recast layer. The study on the machining performance of the powder mixed EDM process related to some parameters like powder concentration, workpiece type, properties, and electrode area. Kumar et al. [6,7] reported reviews on the influence of PMEDM. And they concluded that the material deposit from (Cu-W, Cu), and (Cu-Cr) electrodes to the workpiece(H13) in attendance of
tungsten powder mixed with insulator fluid. Jeswani [8] stated that graphite powder has been suspended to insulation fluid enhanced the material removal rate percent by (60%) and reduced the tool wear ratio by (15%). Kansal et al [9, 10] discovered the influence of process factors to predict the optimal factors for powder mixed EDM using RSM, Taguchi method, multi objective optimization. Singh and Yeh in [11] grey relational analysis was used during machining MMC with mixing SiC powder to optimize multiple out puts .Bhattacharyaa et al.[12]calculated the appropriate factors set for finish surface machining on ( EN-31, H11, HCr) die steel mixing aluminum and Ga powders with using numerous combination of insulated fluid and tool. Singh et al. [13] expected the contribution of input factors on SR during cutting (H11) die steel material using tool from copper material and by mixing Al with insulator fluid. good surface finish was achieved, and opposite polarity was obtained appropriate for decrease the (SR). The study investigated the influence mixing of aluminum and silicon powder to the insulter fluid on the process factors. Maan, Azzam [14-15] investigated the effect of manganese powder on machining performance and surface roughness of different types of die steel and concluded that the manganese powder increase the MRR and reduce the surface roughness. The previous research illustrate that numerous works have been made in the area of ( EDM ) and ( PMEDM ), the outputs have been reported by mixed different type of powder to the dielectric and their effect on the output like machining performance, thickness of white layer, surface roughness, but not enough work has been done on the surface integrity, specifically on the surface hardness by using manganese powder, and mixing this powder with another type like aluminum for machining different type of die steel, therefor this aspect need more investigation. The current research is a step on this way. An effort has been made to obtained the optimum set of machining factors by predict the maximum micro–hardness of the surface by mixing three powders with dielectric.

2. Experimental Method

2.1. Materials and machine
Experiment has been conducted with a die sinking EDM (CM 323+50N (CHMBER EDM), which is available at the University of Technology in Baghdad, in an attached tank put inside work tank as shown in Figure 1. The copper was used to make the electrodes. The workpieces used in the investigation are the die steel (D3, H13, D3), which have chemical and physical properties are shown in Table 1.

![Figure 1 Machine tank](image-url)
Table 1. Chemical composition of workpiece materials

| No | Elements | AISI D3 | H13 | AISI D6 |
|----|----------|---------|-----|---------|
| 1  | C        | 2.55    | 0.45| 2.00    |
| 2  | Si       | 0.26    | 1.2 | 0.4     |
| 3  | Mn       | 0.47    | 1.75| 0.6     |
| 4  | P        | 0.038   | 0.03| 0.03    |
| 5  | S        | 0.056   | 0.03| 0.03    |
| 6  | Cr       | 13      | 12  | 11      |
| 7  | Mo       | 0.08    | -   | -       |
| 8  | Fe       | Balance | balance | Balance |

2.2. Experimental and procedures

The working parameters and their levels are listed in table 2, while the other parameters were considered constant as shown in table 3. Figure 2 shows the system set-up for the machining process. The same steps have been applied in machining with powder Al, Mn, and Al-Mn with mixing ratio is 75% Al and 24% Mn. This was used to compare the effect of three types of powders and their concentration with three types of die steel on the surface hardness of the EDM. The experimental runs have been designed using Taguchi method and the results were analyzed with ANOVA. This method capable of provides information on parameters effects on experimental error with minimum number of runs, it is also flexible. Five factors considered were workpiece, powder types, concentration, current, and pulse on time. Micro-Vickers hardness testing machine has been used to measure the response (hardness (Mitutoyo MVK-H2, Japan). The results have been analyzed with Minitab software (version 18). Experiments have been carried out as per the L27 orthogonal array.

The surfaces were cleaned with oil to remove any accumulated debris at the corners followed by acetone. All the machined surfaces thus obtained were subjected to micro-hardness testing using a load of 500 g for duration of 20 seconds. After machining the micro-hardness was measured at five different places and average values were noted.

Table 2. investigated factors and their levels

| Parameters   | Levels |
|--------------|--------|
| Workpiece    | AISI D3 | H13 | AISI D6 |
| Peak current | 1       | 2   | 3       |
| Pulse on time| 100     | 150 | 200     |
| Concentration| 1       | 2   | 4       |
| Powder       | Al      | Mn  | Al-Mn   |

Table 3. Constant input parameters

| No | Machining parameters     | Fixed value |
|----|--------------------------|-------------|
| 1  | Open circuit value        | 135 ±5      |
| 2  | Polarity                  | straight    |
| 3  | Machining time            | 30 min      |
| 4  | Type of dielectric        | kerosene    |
| 5  | Pulse off time            | 75 µs       |
3. Results and Discussions

A total of 27 experiments had been conducted. Maximize the value of hardness was the goal of the experimentation. (S/N) ratio had been calculated for higher – better type of response characteristic as

\[
(S/N)_{HB} = -10 \log \left[ \frac{1}{R} \sum_{j=1}^{R} (\frac{1}{y_j^2}) \right]_{HB}
\]  

(1)

\( y_j \) = hardness value of the response characteristic  
\( R \) = repetitions number

The amount of variation existing in process had been indicated by the signal/noise ratio. These ratios of micro-hardness have been calculated to identify the contribution ratio of parameters that cause variation in micro-hardness. It is a “Higher the better” type response and it is given by a logarithmic function based on the mean square deviation. The values of micro-hardness have been collected and values of their S/N ratios had been calculated as listed in Table 4.

3.1. Analysis of Variance – Micro-hardness

For recognizing the significant parameters that affect the surface micro hardness, analysis of variance (ANOVA) has been used to analyze the results at 95% confidence interval as listed in Table 5. The F tested has been used to obtain which factor is significant. When F value is high this mean a particular change in the process parameters. ANOVA table shows that F value for, workpiece, powder, concentration, current, pulse on time are 24.38, 30.29, 0.33, 4.24 respectively. The greater the effect on the performance characteristic due to the powder, workpiece, and current which are the factors that significantly affect the micro-hardness. Other factors, namely, pulse on time and concentration were found to be insignificant because their (P value) is more than 0.05%.

The mean values of surface hardness and corresponding single to noise ratio have been calculated to obtain the effect of parameters. The effects of these parameters are shown in Figure 3 and 4. It has been observed that micro-hardness value rises sharply when the current increases from 4 to 8 A. This is due to substantial material transfer at 8 A current. It has also noticed that micro-hardness at 12 A current is higher than its value at 4 A because of more heating and quenching. Micro-hardness increased when the manganese powder has been used compared with aluminum powder and mixing of AL-Mn powder, the reason behind that is, machining with Mn powder results in creation of manganese carbide at the machine surface. Such material more helpful in machining of die steel because it contains low carbon to enhance the hardness of the surface.
| No. | Workpiece | Powder | Concentration (g/L) | Current (A) | Pulse on (µs) | Microhardness (µm) | S/N Ratio |
|-----|-----------|--------|---------------------|-------------|--------------|-------------------|----------|
| 1   | D3        | Al     | 1                   | 4           | 100          | 738               | 57.3611  |
| 2   | D3        | Al     | 2                   | 8           | 150          | 384               | 51.6866  |
| 3   | D3        | Al     | 4                   | 12          | 200          | 1074              | 60.6201  |
| 4   | D3        | Mn     | 1                   | 8           | 150          | 1776              | 64.9889  |
| 5   | D3        | Mn     | 2                   | 12          | 200          | 2601              | 68.3028  |
| 6   | D3        | Mn     | 4                   | 4           | 100          | 1611              | 64.1419  |
| 7   | D3        | Al-Mn  | 1                   | 12          | 200          | 905               | 59.1330  |
| 8   | D3        | Al-Mn  | 2                   | 4           | 100          | 100               | 40.0000  |
| 9   | D3        | Al-Mn  | 4                   | 8           | 150          | 641               | 56.1372  |
| 10  | H13       | Al     | 1                   | 4           | 150          | 531               | 54.5019  |
| 11  | H13       | Al     | 2                   | 8           | 200          | 1248              | 61.9243  |
| 12  | H13       | Al     | 4                   | 12          | 100          | 1030              | 60.2567  |
| 13  | H13       | Mn     | 1                   | 8           | 200          | 1556              | 63.8402  |
| 14  | H13       | Mn     | 2                   | 12          | 100          | 1735              | 64.7860  |
| 15  | H13       | Mn     | 4                   | 4           | 150          | 1500              | 63.5218  |
| 16  | H13       | Al-Mn  | 1                   | 12          | 100          | 1393              | 62.8790  |
| 17  | H13       | Al-Mn  | 2                   | 4           | 150          | 584               | 55.3283  |
| 18  | H13       | Al-Mn  | 4                   | 8           | 200          | 761               | 57.6277  |
| 19  | D6        | Al     | 1                   | 4           | 200          | 1568              | 63.9069  |
| 20  | D6        | Al     | 2                   | 8           | 100          | 1930              | 65.7111  |
| 21  | D6        | Al     | 4                   | 12          | 150          | 1743              | 64.8259  |
| 22  | D6        | Mn     | 1                   | 8           | 100          | 2894              | 69.2300  |
| 23  | D6        | Mn     | 2                   | 12          | 150          | 2166              | 66.7132  |
| 24  | D6        | Mn     | 4                   | 4           | 200          | 2560              | 68.1648  |
| 25  | D6        | Al-Mn  | 1                   | 12          | 150          | 1861              | 65.3949  |
| 26  | D6        | Al-Mn  | 2                   | 4           | 200          | 1450              | 63.2274  |
| 27  | D6        | Al-Mn  | 4                   | 8           | 100          | 1650              | 64.3497  |

Micro-hardness decreased when pulse on increasing from level (100 µs) to (150 µs) and then increased at (200 µs) because of higher heating effect at (200 µs) which is responsible for improving Micro-hardness. Table 6 and 7 shows the ranks of various factors for mean and S/N in the terms of their relative significance. Powder has the highest rank; signifying highest contribution to Micro-hardness and concentration has the lowest rank and was observed to be insignificant in affecting Micro-hardness.
Table 5. ANOVA for Micro-hardness

| Source          | DF | Seq SS  | Adj MS  | F-test | P value | C% |
|-----------------|----|---------|---------|--------|---------|----|
| Workpiece       | 2  | 4449644 | 2224822 | 24.38  | 0.000   | 35 |
| Powder          | 2  | 5528079 | 2764039 | 30.29  | 0.000   | 43.5 |
| Concentration   | 2  | 59706   | 29853   | 0.33   | 0.726   | 0.47 |
| Currant         | 2  | 835533  | 417766  | 4.58   | 0.027   | 6.57 |
| Pulse on time   | 2  | 386650  | 193325  | 2.12   | 0.153   | 3.04 |
| Error           | 16 | 1459869 | 91242   |        |         |    |
| Total           | 26 | 12719481|         |        |         |    |
| S = 302.063     |    |         |         |        |         |    |
| DF=Degree of freedom | SS=sum of squares | R-Sq = 88.52% | R-Sq(adj) = 81.35% | C=contribution |

Table 6. ANOVA of mean for Micro-hardness larger is better

| Level | Workpiece | Powder | Concentration | Currant | Ton |
|-------|-----------|--------|---------------|---------|-----|
| 1     | 1092      | 1138   | 1469          | 1182    | 1453|
| 2     | 1149      | 2044   | 1355          | 1427    | 1243|
| 3     | 1980      | 1038   | 1397          | 1612    | 1525|
| Delta | 888       | 1006   | 114           | 430     | 282 |
| Rank  | 2         | 1      | 5             | 3       | 4   |

Figure 3. Main effects plot of mean for Micro-hardness
Table 7. ANOVA of S/N for Micro-hardness larger is better

| Level | Workpiece | Powder | Concentration | Currant | Ton |
|-------|-----------|--------|---------------|---------|-----|
| 1     | 58.04     | 60.09  | 62.36         | 58.91   | 60.97|
| 2     | 60.52     | 65.97  | 59.74         | 61.72   | 60.34|
| 3     | 65.72     | 58.23  | 62.18         | 63.66   | 62.97|
| Delta | 7.68      | 7.73   | 2.62          | 4.75    | 2.63|
| Rank  | 2         | 1      | 5             | 3       | 4   |

Figure 4. Main effects plot of S/N ratios for Micro-hardness

3.2. Optimal Design
The mean effect plot as shown in Figure 3 has been used to estimate optimum value of micro-hardness with optimal design conditions through the Equation 2 after eliminate the non-significant parameters. From Table 7, it is concluded that highest Micro-hardness is achieved when manganese powder, powder concentration (1g/l), pulse on time (200 µs) and current (12A) were selected in the experimental trial. In S/N ratio, highest of Micro-hardness. Figure 4 was found when pulse on time (200µs) and current (12Amp) were selected in experimental trial. Theoretical optimum value(η) under the optimum conditions, is given by

\[ \eta_{opt} = m + (m_{A3} - m) + (m_{B2} - m) + (m_{D3} - m) \]

\[ = 61.43 + (65.72 - 61.43) + (65.97 - 61.43) + (63.66 - 61.43) = 72.4 \]

Micro-hardness under these optimum conditions, \( Y_{opt} \) calculated by

\[ Y_{opt}^2 = \frac{1}{10} \eta_{opt} \]

\[ Y_{opt} = 4192 \text{ HV} \]

3.3. Conformation test
These optimum input process factors did not find in the table of orthogonal array of results, the confirmation test has been conducted with these optioned optimum values. The value of micro-hardness
in confirmation test has been found to be 3995 HV which is very close to the value predicted by Taguchi analysis and the percentage of error was 4.7%.

4. Conclusions
The following conclusions are drawn from the present work:
1. The mixing of manganese powder with dielectric results in high M-hardness compared with aluminum powder and mixed powder of aluminum and manganese.
2. Maximum M-hardness is obtained at workpiece (D6), powder (Mn), concentration (1g/L), a peak current of (12 A), and Pulse on (200 µs).
3. The significant factors for M-hardness are workpiece, powder type, and current. The parameter of pulse on time and concentration has no significant effect on M-hardness.

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