

Comparison of Surface Characteristics and Micro Hardness of AISI D2 Tool Steel and LM13 Aluminum Alloy Machined under dry EDM (Green Machining) Process

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In this experimental work, the micro structure and the micro hardness of the surfaces machined under the dry EDM process is analyzed for AISI D2 tool steel and LM13 aluminum alloy. The experiments were conducted using copper tool electrode. Few modifications were made in the tool for conducting the experiments under dry EDM process. Discharge current, pulse on time, voltage, pressure, tool rotational speed and the duty factor were used as the various process parameters and their influence over the micro structure and micro hardness of the machined surfaces were analyzed. Better results were observed in the dry EDM process for AISI D2 tool steel, whereas dry EDM process did not reveal appreciable results for LM13 aluminum alloy.

Keywords: dry EDM, conventional EDM, micro structure, micro hardness.

1. INTRODUCTION

Electrical discharge machining (EDM) is a widely accepted machining process used for machining the hard materials. EDM is also applied extensively because of its ability to machine complex shapes with great accuracy. The discharge of spark in the inter electrode gap enables the removal of material from the work piece [1]. The problems like vibration, chattering and stresses are greatly reduced in EDM due to the absence of direct contact between the tool and the work piece. Materials of any hardness, toughness and thickness can be machined accurately, since EDM process is not constrained by the physical properties of the materials [2]. Ranjan et al (2020) [3] employed a metamodel coupled with global optimization approach to maximize productivity in EDM process. MRR and TWR are expressed as functions of current, pulse on-time and pulse off-time and observed 21% and 2% better performance in TWR and MRR respectively.

Regardless of these advantages, there are also some shortcomings, which need to be overcome. The major disadvantage is the formation of toxic fumes due to the breakdown of the hydrocarbon oil based dielectric fluids [4]. The usage of dielectric fluids not only leads to environment hazards, but also has severe economical impact [5]. The government is also taking many initiatives to transform towards Green Manufacturing and reducing the industrial pollution.

Dry EDM (DEDM) is one of the green manufacturing processes where a gas is used as dielectric medium that replaces the liquid dielectric. The first attempt of DEDM was made to avoid the usage of hydrocarbon oil

in EDM, consideration of environmental preservation [4]. In DEDM process, a high velocity gas under high pressure is flushed into the inter-electrode gap, facilitating the effective removal of the debris particles, and thereby increasing the material removal rate (MRR) [6].

The concept of green manufacturing attracted many researchers to work on DEDM process and a lot of improvements are still in progress. Zero tool wear, lower surface roughness values, formation of very thin white layer, smaller HAZ and lower residual stress were reported by most of the authors [7-10]. Higher MRR was reported in the ultrasonic assisted DEDM process at the expense of surface roughness. In this experiment, ultrasonic vibrations were given to the work piece [11]. Later, some experiments were conducted in DEDM process by providing ultrasonic vibrations to the tool [12].

Kunieda et al (1997) [13] conducted experiments under DEDM process using a tubular electrode, and a central core was observed in the machined surface due to the non machining area of the tubular region. A special tool design was proposed for drilling the holes without formation of the central core [7]. Saha et al (2009) [8] conducted experiments under DEDM process using a copper tool with non central holes. A tubular electrode with rectangular slots cut on the periphery of the tubular tool was proposed and improvement in MRR was observed [14]. Rectangular slots were cut on the periphery of the tool, which enabled the effective flushing of the debris particles. Pragadish et al (2015) [15] proposed a special tool design for conducting experiments under DEDM process, and observed improvement in the characteristics of the machined surface.

Many researchers have attempted to achieve effective machining in dry EDM process. Initially the tubular electrodes were used for machining in dry EDM to ensure the effective passage of the gas in the inter-

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electrode gap. But drilling of blind holes is not impossible with tubular electrode due to the formation of the central core. Later, many tool designs were proposed by the researchers to achieve better machining as discussed above. An attempt is made in this experimental work also with some modifications in the existing tool design to achieve better machining characteristics.

It is well known that EDM process is widely used to machine the hard materials. The main application of this work is (i) to achieve environment friendly – green machining process, where the toxic effects produced in conventional EDM processes are greatly avoided, and (ii) to improve the machining characteristics.

In this research work, a modified tool design was used to drill holes in the AISI D2 tool steel and LM13 aluminum alloy. A special attachment was fabricated to enable the rotation of the tool, which is very essential to conduct the experiments under DEDM process. The characteristics of the surfaces machined and the variation of the micro hardness for both the materials is compared.

2. EXPERIMENTAL DETAILS

2.1 Experimental Set-up

Electronica Xpert 1 type CNC Die sinking EDM machine was used for conducting the experiments and, the three axis movement of the machine tool was achieved with a DC servo system. Since, the stability of the process and the flow of the dielectric can be enhanced by providing rotational motion to the tool, a special attachment was fabricated and attached to the EDM machine, to enable the rotation of the tool. The fabricated set up attached with the EDM machine is shown in the Fig. 1.

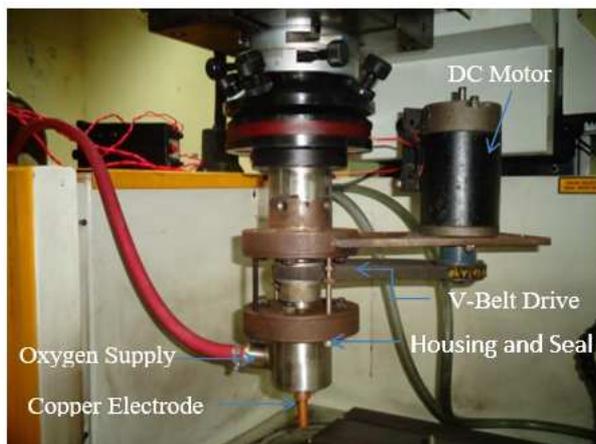


Figure 1. Dry EDM Set-up

2.2 Workpiece, tool and dielectric medium

EDM experiments were conducted in the AISI D2 tool steel and LM13 aluminum alloy work pieces with the dimensions of 30 mm x 30 mm x 15 mm. A cylindrical copper rod was chosen as the tool electrode. Oxygen was used as the dielectric medium, since the combination of the copper tool and oxygen gas was proven as the optimal combination for the dry EDM process [16]. A special design was adapted to conduct the experiments in the dry EDM process.

2.3 Electrode design for dry EDM process

In the dry EDM process, a high velocity gas is made to flow through a rotating tubular electrode. A central core will be formed in the drilled surface, if the tubular electrode is used, due to the non availability of the material in the tool, and cannot be used to drill the blind holes. Special tool designs were proposed for drilling the holes without core, and to achieve efficient flushing in the dry EDM process [7, 8, 14].

For our experimental work, a special modified tool design [15] was proposed for drilling the holes without core in the dry EDM process. Three holes of 2 mm diameter were drilled at 5 mm, 6 mm and 7 mm pitch circle diameter along 120° on the face of the tool. Despite of improved machining, frequent short circuiting was observed due to the improper removal of the debris particles [17]. To overcome this problem, 2 mm x 2 mm rectangular slots were cut along the circumference of the tool, on the alternate 120° of the tool region, where the holes were drilled as shown in the Fig. 2. This design was very effective for drilling holes in the AISI D2 tool steel, but not effective for drilling holes in the LM13 aluminum alloy. The slot length was not sufficient for flushing the debris particles, and hence, the slots were cut for a length of 3 mm for conducting the experiments in the LM13 aluminum alloy.



Figure 2. Drilled copper electrode with slots

2.4 Process parameters

Current (I), pulse-on-time (μ s), voltage (V) and pressure (kPa) were chosen as the varying parameters, whereas tool rotational speed (N) and duty factor were chosen as the fixed parameters. The different values chosen for the process parameters are shown in the Table 1.

Table 1. Experimental details

S. No	Description	AISI D2 tool steel	LM13 Aluminum alloy
1.	Electrode	Copper	Copper
2.	Current (A)	8, 10 and 12	4, 6 and 8
3.	Pulse on time (μ s)	100, 150 and 200	100, 150 and 200
4.	Gap voltage (V)	50, 60 and 70	50, 60 and 70
5.	Oxygen Pressure (kPa)	1.5, 2.0 and 2.5	1.5, 2.0 and 2.5
6.	Tool rotational speed (rpm)	1500	1500
7.	Dielectric medium	Oxygen	Oxygen

Machining of LM13 aluminum alloy in the DEDM process was difficult due to the combination of the particles having different melting point temperatures in the work pieces, and the lower dielectric strength of the oxygen. Unstable machining conditions were observed for the higher values of current in machining of LM13 alloy under the DEDM process. Hence, the values of the current were chosen as 4 A, 6 A and 8 A.

Table 2. Experimental layout for the process parameters (for AISI D2 tool steel)

S. No	Current (A)	Pulse on time (μ s)	Gap Voltage (V)	Pressure (Kpa)
1	8	100	50	1.5
2	8	100	60	2
3	8	100	70	2.5
4	8	150	50	2
5	8	150	60	2.5
6	8	150	70	1.5
7	8	200	50	2.5
8	8	200	60	1.5
9	8	200	70	2
10	10	100	50	2.5
11	10	100	60	1.5
12	10	100	70	2
13	10	150	50	1.5
14	10	150	60	2
15	10	150	70	2.5
16	10	200	50	2
17	10	200	60	2.5
18	10	200	70	1.5
19	12	100	50	2
20	12	100	60	2.5
21	12	100	70	1.5
22	12	150	50	2.5
23	12	150	60	1.5
24	12	150	70	2
25	12	200	50	1.5
26	12	200	60	2
27	12	200	70	2.5

Taguchi method is an effective tool for optimizing the problem with minimum number of experiments, which involves many input parameters and single response variable. Taguchi L27 orthogonal array was designed and the experiments were conducted accordingly. The experimental layout for the process parameters are shown in the Table2 and Table 3 for AISI D2 tool steel and LM13 aluminum alloy respectively.

Table 3. Experimental layout for the process parameters (for LM13 aluminum alloy)

S. No	Current (A)	Pulse on time (μ s)	Gap Voltage (V)	Pressure (Kpa)
1	4	100	50	1.5
2	4	100	60	2
3	4	100	70	2.5
4	4	150	50	2
5	4	150	60	2.5
6	4	150	70	1.5
7	4	200	50	2.5
8	4	200	60	1.5
9	4	200	70	2
10	6	100	50	2.5

11	6	100	60	1.5
12	6	100	70	2
13	6	150	50	1.5
14	6	150	60	2
15	6	150	70	2.5
16	6	200	50	2
17	6	200	60	2.5
18	6	200	70	1.5
19	8	100	50	2
20	8	100	60	2.5
21	8	100	70	1.5
22	8	150	50	2.5
23	8	150	60	1.5
24	8	150	70	2
25	8	200	50	1.5
26	8	200	60	2
27	8	200	70	2.5

3. RESULTS AND DISCUSSION

3.1 Surface morphology

Figure 3 (a) – (c) shows the SEM images of the machined surfaces of AISI D2 tool steel and LM13 aluminum alloy for low level, middle level and high level process parameters respectively. Formation of cracks can be observed for almost all the machined surfaces. Since EDM process involves heating to high temperatures followed by sudden cooling, the formation of cracks is inevitable. Better surface morphology is observed for the surfaces of AISI D2 tool steel, compared to LM13 aluminum alloy for all the levels of process parameters.

Attachment of debris particles is observed for both the materials. But the reattachment of particles seems to decrease with increasing values of pressure. This is due to increase in the flushing efficiency at higher pressure values. More uneven surfaces are observed for LM13 aluminum alloy. This may be due to severe arcing problem. LM13 aluminum alloy is composed of aluminum and silicon particles, which have more difference in their melting point temperatures. Since oxygen has less dielectric strength, compared to the dielectric fluids, less amount of energy is released during the process. This effectively melts the aluminum particles and the silicon particles are not melted and removed properly. Therefore, the silicon particles stand as peaks and lead to arcing or uneven machining. Wider and lengthy cracks are observed on the surfaces of LM13 aluminum alloy compared to AISI D2 tool steel.

The machined surfaces of AISI D2 tool steel exhibits better characteristics compared to the LM13 aluminum alloy. AISI D2 tool steel reveals better characteristics for middle level parameters. At lower levels, the flushing is not effective due to lower pressure. For LM13 aluminum alloy, better characteristics are observed under higher parameters. This may be due to release of high energy at higher values of current and effective flushing at high pressure.

3.2 Micro hardness

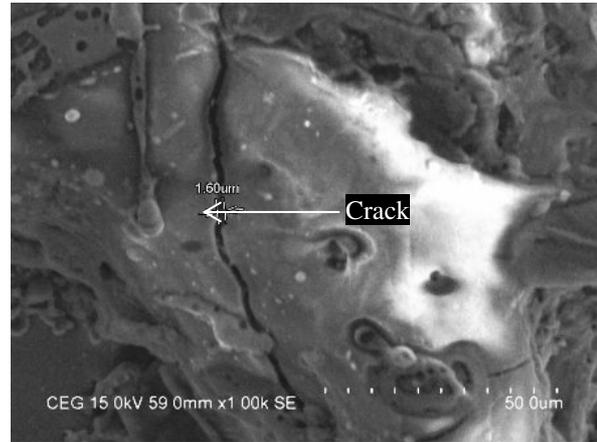
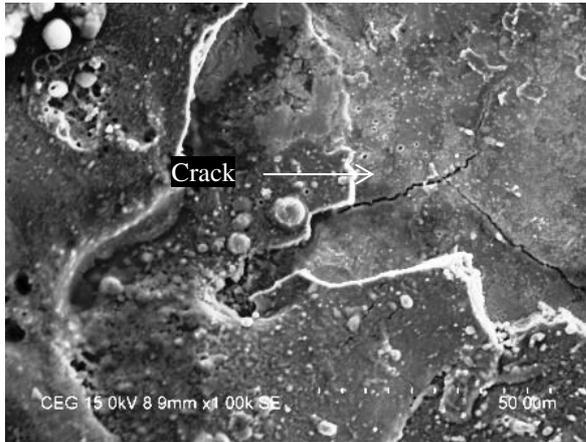
Figure 4 (a) – (b) shows the micro hardness survey of AISI D2 tool steel and LM13 aluminum alloy machined

under different levels of parameters under conventional EDM process and DEDM process. But in this paper, the variations for DEDM process alone are analyzed. For AISI D2 tool steel, higher values of hardness are observed near the machined edge. The variation is noticed more for the higher values of DEDM process (curve D3). More heat energy is produced at higher levels of parameters and it is followed by sudden cooling, which favors the formation of white layer. This may be the reason for the higher hardness values near

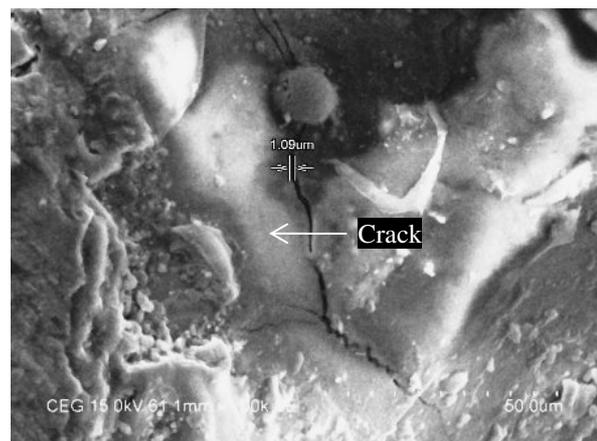
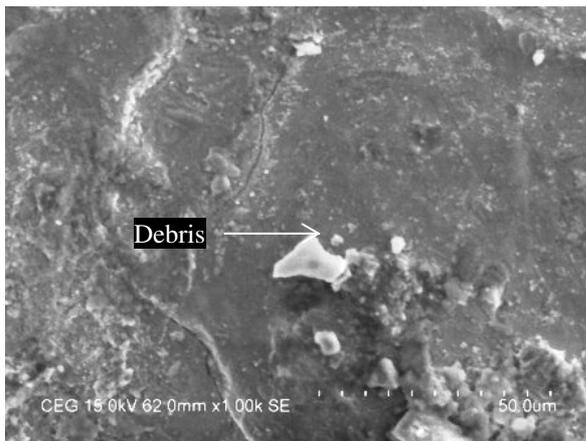
the machined edge. Lower hardness values are observed for LM13 aluminum alloy under DEDM process compared to the normal process. No appreciable variation is observed in the hardness values of LM13 aluminum alloy with depth. Slightly higher hardness value is observed for the specimen machined under higher values of parameters (D3). This is due to release of more energy at higher values, since the energy produced is directly proportional to the current, voltage and pulse on time.

AISI D2 tool steel

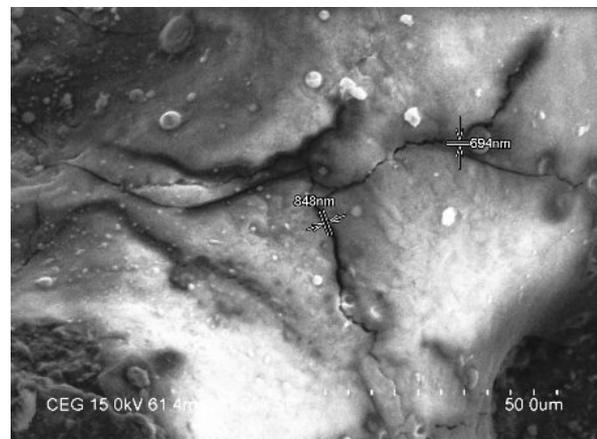
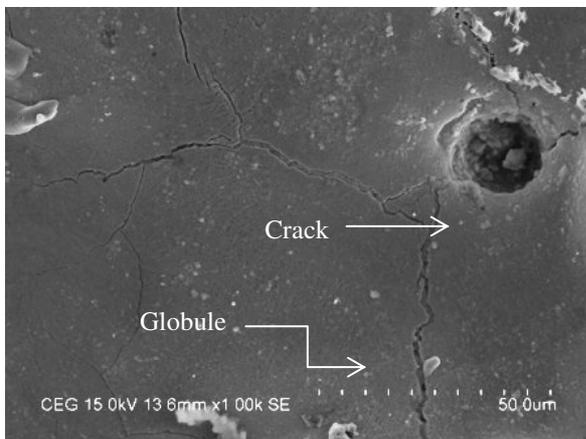
LM13 aluminum alloy



(a) Current = 8 A, Pulse-on-time = 100 μ s, Pressure = 1.5 kPa (for LM13 aluminum alloy, I = 4 A)

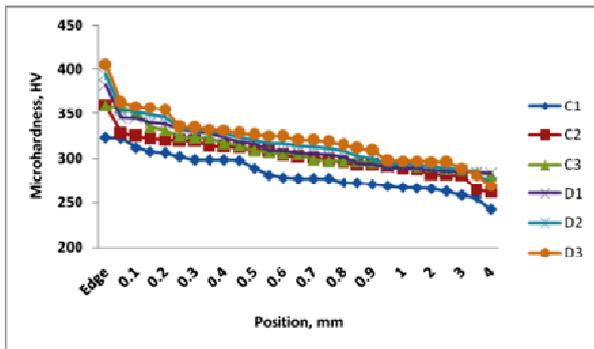


(b) Current = 10 A, Pulse-on-time = 150 μ s, Pressure = 2.0 kPa (for LM13 aluminum alloy, I = 6 A)

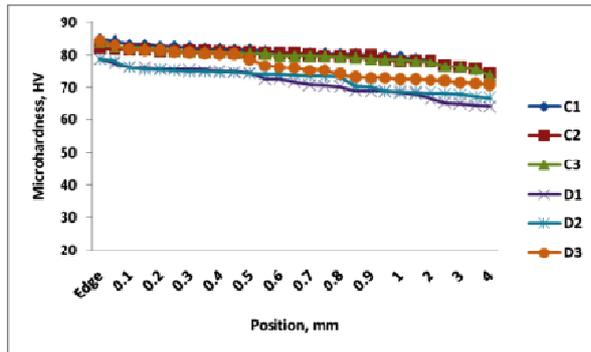


(c) Current = 12 A, Pulse-on-time = 200 μ s, Pressure = 2.5 kPa (for LM13 aluminum alloy, I = 8 A)

Figure 3. (a) – (c) SEM Images of the Machined Surface under DEDM Process for AISI D2 Tool Steel and LM13 Aluminum Alloy



(a) AISI D2 tool steel



(b) LM13 aluminum alloy

C – Conventional EDM

D – Dry EDM

(1,2,3 represents low, medium and high level respectively)

Figure 4. (a) – (b) Variation of micro hardness

4. CONCLUSION

Experiments were conducted on AISI D2 tool steel and LM13 aluminum alloy under DEDM process. The experiment was conducted using a modified tool design. The machined surfaces were analyzed and the following solutions are arrived at.

- (1) Holes were drilled effectively without any core with the proposed tool design.
- (2) The machined surfaces of AISI D2 tool and LM13 aluminum alloy were examined using SEM images. The machined surfaces of AISI D2 tool steel exhibited better characteristics compared to LM13 aluminum alloy.
- (3) The micro hardness survey also reveals some variation in the hardness values of AISI D2 tool steel and no appreciable variations are noticed for LM13 aluminum alloy.
- (4) From the analysis it is visible that better characteristics were observed for AISI D2 tool steel, whereas LM13 aluminum alloy revealed poor machining characteristics under DEDM process. This is due to the combination of particles with different melting points and hardness in LM13 aluminum alloy.

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**УПОРЕЂИВАЊЕ КАРАКТЕРИСТИКА
ПОВРШИНЕ И МИКРОТВРДОЋЕ AISI D2
АЛАТНОГ ЧЕЛИКА И LM13 ЛЕГУРЕ
АЛУМИНИЈУМА ОБРАЂИВАНИХ**

**ПОСТУПКОМ СУВЕ ЕЛЕКТРО-ЕРОЗИОНЕ
ОБРАДЕ (ПРОЦЕС ЗЕЛЕНЕ ОБРАДЕ)**

Н. Прагадиш, М.П. Кумар

У овом експерименталном раду анализира се микро-структура и микротврдоћа површина AISI D2 алатног челика и LM13 легуре алуминијума обрађиваних сувим електро-ерозионим поступком. Експерименти су изведени коришћењем бакарне електроде за алат, која је модификована за експерименталне услове електро-ерозионе обраде. Струја пражњења, укључивање импулса, напон, притисак, брзина ротације алата и радни циклус су узети за параметре процеса обраде и анализиран је њихова утицај на микроструктуру и микротврдоћу обрађених површина. Сувом електро-ерозионом обрадом добијени су бољи резултати код алатног челика, док су код легуре алуминијума били занемарљиви.