A Review on Electric Discharge Machining: The Role of MCDM, Dielectric Fluids, and Experimental Design Plans

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ABSTRACT

Electrical Discharge Machining (EDM) is a advanced technique used for machining intricate and high-strength materials. This study examines how Multi-Criteria Decision Making (MCDM) methodologies are used to optimize EDM parameters for a variety of materials, including as titanium alloy, tungsten carbide and others materials.EDM oil plays a vital role as a dielectric fluid like vegetable oil, kerosene, and mineral water which removes debris, cool the work piece and explored for their efficiency. Design plan like L_9, L_{16}, L_{25} and L_{27} orthogonal array (OA), CCD and MCDM techniques like AHP, MOORA, TOPSIS, GRA, and DEAR . This comprehensive analysis helps for researchers and industries aiming to enhance EDM efficiency and performance.

Keywords: EDM, Dielectric, Design plan, Techquniue, orthogonal array.

1. **History of EDM:** The electrical discharge machining was discovered as early as 1770 by Joseph Priestley, and its erosion effect of the electric spark was found in an uncontrolled manner. Later, in the year 1943, two Soviet scientists, B.L.Minz and M.L. Lazarenko pointed out that the wear of precious metals was affected negatively by the electric current and this current was utilized in a controlled manner to remove the work materials, therefore this method was named electric discharge and spark erosion machining [1-3].
2. **Introduction of EDM** Today, the EDM has revolutionized the advanced manufacturing field for the creation of complex shapes.Electrical discharge machining involves controlled electric spark discharges between the tool (cathode) and work piece (anode), causing a thermal erosion process [3-4]. This leads to the work piece taking on the form of the tool. The erosion is caused by electrical discharges between the (0.005–0.05 mm) is always kept between the tool and the work piece during the EDM operation [5,8-9]. Within a dielectric substance, commonly a liquid, spark discharge occurs across gaps between the electrodes [10].During EDM, the work piece and electrode sit within a dielectric liquid like de-ionized water, kerosene, or EDM oil. Voltage is created within the narrow space between them, leading to the creation of an ionized path. This results in high-frequency electric discharges being produced between the electrode and the work piece. [6,11]. Electric sparks create incredibly hot temperatures, ranging between 8000 and 15,000 degrees Celsius. This extreme heat melts or turns materials into vapor on both the tool and work piece, taking material from the work piece [12]. As the process concludes, the plasma temperature rapidly decreases, and the work piece begins to cool. Waste residues, formed by spark erosion, are flushed away as debris by the dielectric medium [7,13].EDM is employed in a wide range of industrial applications

for precise machining of conductive materials, particularly in scenarios where conventional approaches struggle caused by material hardness or intricate shapes. It's commonly applied in the aerospace, automotive, medical device manufacturing, and tooling industries focused on precision component production like molds, dies, and prototypes. EDM is favored for its ability to work with hardened materials and create detailed shapes with high precision [14–15].

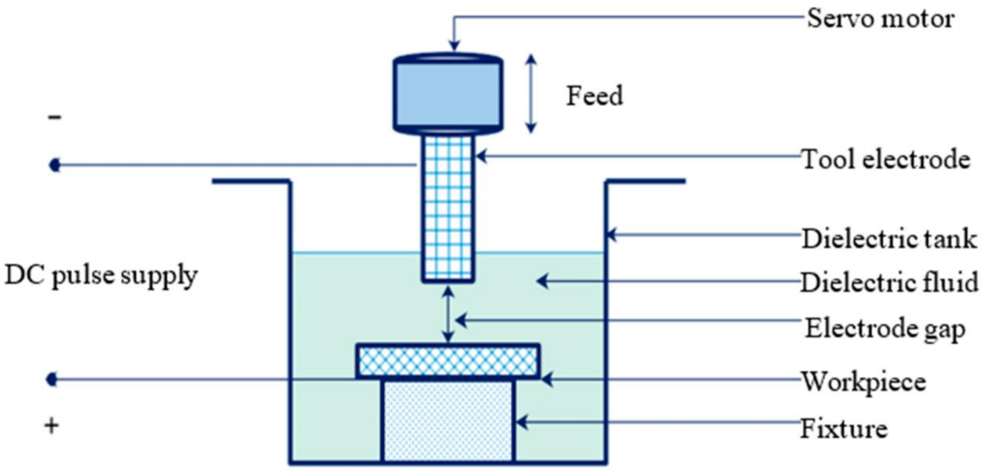


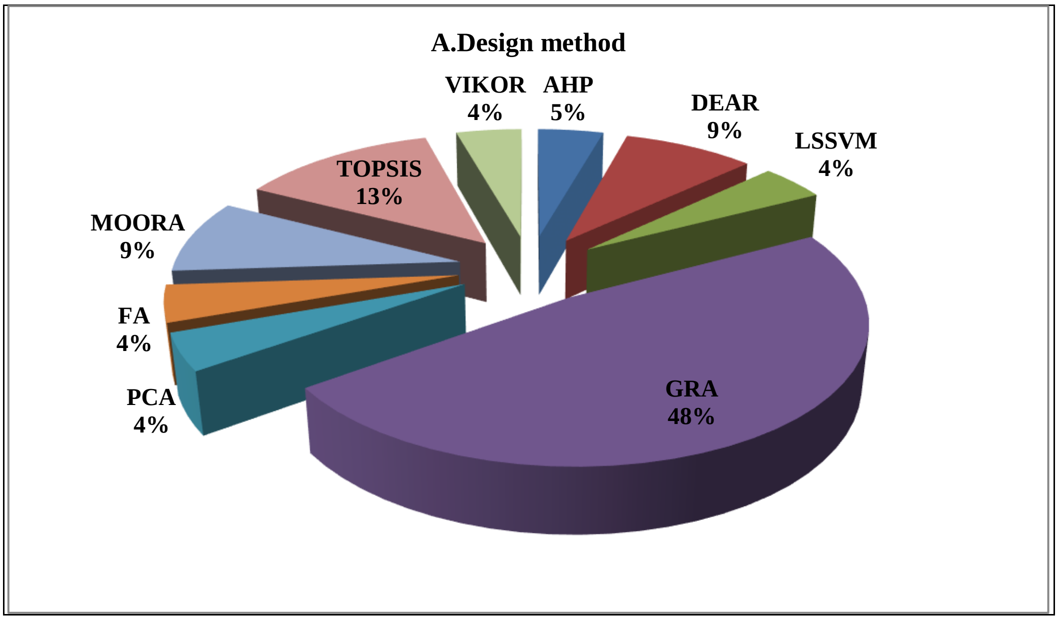
Figure 1 Schematic of an EDM process [36].

3. **Literature review:** The main objective of this paper is to critically review the applications of various MCDM methods, dielectrics and design of experiment. This review article analyzes 32 papers, extracting relevant information such as, plan design, MCDM method, dielectric and work material. The results of the analysis are presented in pie chart form to help fellow researchers in various dimensions such as the number of input parameters and their level, the appropriate dielectric (EDM oil, vegetable, water, Kerosene, Distilled water and paraffin oil) used, experimental design (L9, L16, L25, and L28) and the MCDM method like AHP, MOORA, TOPSIS, VIKOR, DEAR, GRA etc.

Table.1 EDM Process Studies: Materials, Dielectrics, and Design Methods

Sr. No	Material	Dielectric	Experimental design plan	Design Method	References
1	Al MMC	EDM oil	L18	AHP	Sidhu, S. S., et al [16]
2	Ti-6Al-4V	Vegetable oil	L9	MOORA	Srikanth, R., et al [17]
3	Titanium grade 9	Mineral water	L9	MOORA, GA	Kumar, A., et al[18]
4	Ti-6Al-4V	Distilled water	CCD	TOPSIS	Rajamanickam, S., et al [19]
5	Ti-6Al-4V	Kerosene	L9	TOPSIS	Sharma, A. K., et al[20]
6	Ti-6Al-4V	EDM oil	L27	TOPSIS, QPSO	Sahu, A. K., et al[21]
7	Titanium alloy	EDM oil	CCD	VIKOR	Gangil, M., et al. (2018a)[22]

8	Ti-6Al-4V	EDM oil	L9	DEAR	Vaddi, V. R., et al[23]
9	Ti alloy	Water	L16	DEAR	Phan, N. H., et al[24]
10	Titanium alloy	EDM Oil	L27	GRA	Laxman, J., et al[[25]
11	Ti-6Al-4V	IPOL spark erosion oil	L18	GRA	Mhatre, M. S., et al[26]
12	Ti-6A-4V	EDM oil	L16	GRA	Xess, P. A., et al[27]
13	Tungsten carbide	Paraffin oil	L9	GRA	Nayak, S., et al[28]
14	Ti-6Al-4V	Water, oil	L18	GRA	Gaikwad, S., et al[289]
15	Ti-6Al-4V	EDM oil	L25	GRA	Priyadarshini, M., et al. [30]
16	Ti-6Al-4V	EDM oil + surfactant	L9	GRA	Kolli, M., et al[31]
17	Ti-6Al-4V	EDM oil	CCD	GRA, PCA	Gangil, M., et al[32]
18	Ti-6Al-4V	EDM oil	L9	GRA	Kumar, R., et al[33]
19	Ti-4Al-6V	EDM oil	L27	GRA,FA,LSSVM	Sahu, A. K., et al.[34]
20	Nimonic 75	Deionized water	L18	GRA	Singh, M., et al.[35]



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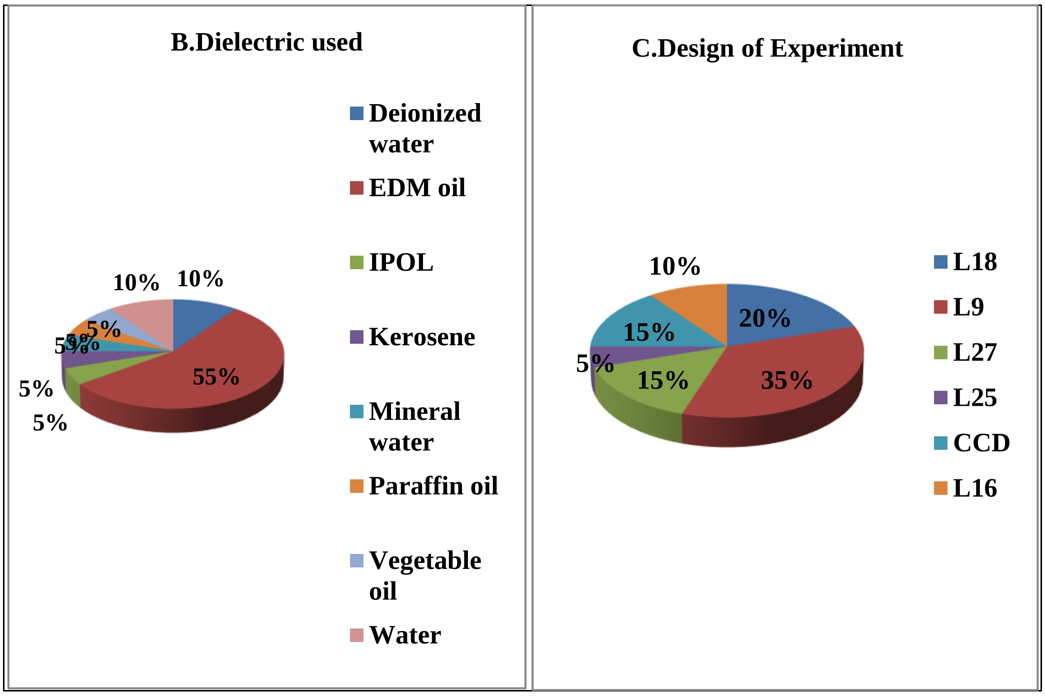

Figure 2: Graphical representation of the reviewed paper in terms of (A) Design method (B) Dielectric used (C) Design of experiment

3. **Results and discussion:** The primary purposes of this review article are to explore the applications of various MCDM techniques as multi-objective for improving the machining performance of EDM. The shortlisted research works are studied to extract the relevant information with respect to experimental dielectrics used, design plans work materials machined and techniques used. The results of these analyses are graphically presented in Figure 2.It can be noticed from Figure 2 (a) provides information on the different types of experimental design observed in previous studies. L9 OA (3 5%) has been used the most in this study, followed by L18 (20%) CCD (1 5%) L27 (1 5%) and L25 (5%).Figure 2 (b) provides information on the different types of dielectric materials used by previous researchers. EDM oil is the most commonly used dielectric (55%), followed by de-ionized water (10%) and normal water (10%).Figure 2 (c) presents the details of various MCDM methods used for optimization of EDM processes in the reviewed research articles. Maximum application of GRA technique has been found (48%), followed by TOPSIS (13%), MOORA (9%), DEAR (9%) and VICOR (4%) methods. Additionally, other MCDM methods such as F.A., P.C.A., A.H.P., and L.S.S.V.M. have also been used for optimization purposes.
4. **Conclusions:** This study offers critical insights into the application of MCDM techniques in optimizing EDM processes:

- In this study research has found that Ti-6Al-4V and other titanium alloys are commonly used in work pieces; EDM oil has been found to be the best dielectric medium. Also, alternative dielectrics like vegetable oil and mineral water work for best result and sustainable manufacturing.
- The study emphasizes the importance of MCDM techniques in advancing EDM applications, as these techniques help improve sustainability and productivity when machining complex materials

- Orthogonal array such as L_9 OA, L_{18} OA, L_{27} OA, and CCD, along with MCDM methods like TOPSIS, GRA, MOORA and DEAR, are effective in parameter optimization and enhance the processes.

5. **Future Research direction**: The directions for research and development in Electrical Discharge Machining (EDM) investigate sustainable dielectric fluids like jatropha oil, neem oil and environment friendly for improving performance of machining Additionally, developing more advanced MCDM technologies and researching smart materials like composites, titanium alloys, and bio-identical new is important for its industrial uses.

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