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Challenges and Advancements in Machining Lithium Disilicate Ceramic for Dental Restorations: A Study on W-ECDM Techniques

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***Abstract* - The use of restorative techniques and trends has evolved over time. Certain material advancements have significantly transformed the field of dentistry, while some original concepts have faded into insignificance. Today, the field of dentistry continues to expand the use of all-ceramic restorations, from pressed-ceramic techniques and materials to the increasing use of zirconia and new materials derived from CAD/CAM technology. In this article, we examine the challenges of slicing lithium disilicate ceramic material using the mist flow-aided W-ECDM process. Due to its superior properties, lithium disilicate ceramic ingots are widely used in dental applications and have gained significant popularity in dental reconstruction. This paper investigates the general challenges associated with micromachining lithium disilicate ceramic ingots using the wire-ECDM process and explores how its composition contributes to these difficulties. The surface morphology of the machined material is also examined in this study.**
***Keywords:* Lithium Disilicate Ceramic, Wire-ECDM Process, All-Ceramic Restorations, Dental Applications, Surface Morphology**

I. INTRODUCTION

Today's rapidly advancing technology demands materials with increasingly rigid specifications for each new application. The industrial sector requires machines with higher output rates, enhanced dependability, longer service lives, greater precision, and resilience to harsh operating environments. Scientists and manufacturers have played a key role in the development of engineering ceramics over the last 50 years. During this time, researchers have introduced advancements in the field of machining and micromachining.

However, these developments have been largely limited to conductive materials [5], leading researchers to explore a hybrid machining technology known as Wire Electrochemical Discharge Machining (W-ECDM), which combines the principles of Electrochemical Machining (ECM) and Wire Electric Discharge Machining (W-EDM) [1]. W-ECDM offers the advantage of machining electrically non-conductive and brittle materials. The first application of this process was carried out by Taylor [2], who observed the development of an electrical discharge at the anode tip in 1925. Later, in 1968, Karafuji and Suda [3] used ECDM to drill glass. The W-ECDM process has since proven to be promising for micromachining composites [17], glass, ceramics, and other materials.

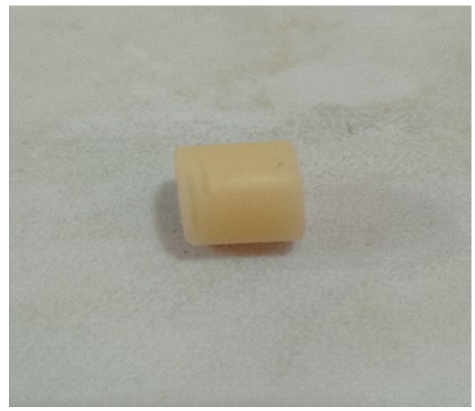

Fig. 1 Lithium Disilicate Ceramic

The wire electrochemical discharge machining (W-ECDM) setup [4], [5] (Fig. 2) consists of two electrodes: the tool cathode, which is typically the wire or workpiece, and the auxiliary anode, which is placed in a machining chamber containing an electrolyte solution. The electrolysis process is activated when DC power is applied to the workpiece, generating hydrogen bubbles around the wire-electrode area and oxygen around the anode region [18]. As the voltage is gradually increased, the number of hydrogen gas bubbles rises. These bubbles coalesce to form a gas layer around the wire, creating a gas film. The current density also increases with the voltage [4]. When the applied voltage exceeds a critical value, the electric field intensifies, resulting in a sparking phenomenon through the gas film. The temperature at the sparking zone increases to a very high level, approaching the melting point of the workpiece [5].

As a result, material removal occurred through the processes of melting, vaporizing, and chemical etching at the machining zone. The fumes [6] (gas) produced during the machining process are typically hazardous to human health. Ghosh *et al.,* stated that sparks are generated due to the electrical switching process, not the breakdown of the protective gas layer [7]. Yang *et al.,* improved the machining performance of Pyrex glass in W-ECDM by adding abrasives to the electrolyte. They reported that bubbles were more vigorous in KOH electrolytes, forming a thick gas film layer.

To fully understand the machining potential of the process, numerous researchers have investigated W-ECDM on various workpieces over the years. By incorporating inductance into the circuit, Basak *et al.,* [9] clarified the operating principles of the ECDM process. In their investigation, electrolytes with 15% and 35% concentrations of KOH and NaOH, respectively, were used. It was discovered that adding inductance increased the machining rate and could be utilized as an additional control parameter. Most of the study focused on the tool-to-electrolyte switching process. Paul *et al.,* [10] used 0.28 mm-diameter stainless steel wire to perform micro-drilling on a 0.5 mm thick silicon chip. They investigated the effects of optimal voltage, electrolyte concentration, and duty factor on the material removal rate (MRR), depth of cut (DOC), and heat-affected zone (HAZ) using the Grey Relational Analysis approach. Scanning electron microscopy (SEM) images were used to measure the number of micro-fractures on the surface, and the results showed that reducing the duty factor had this effect.

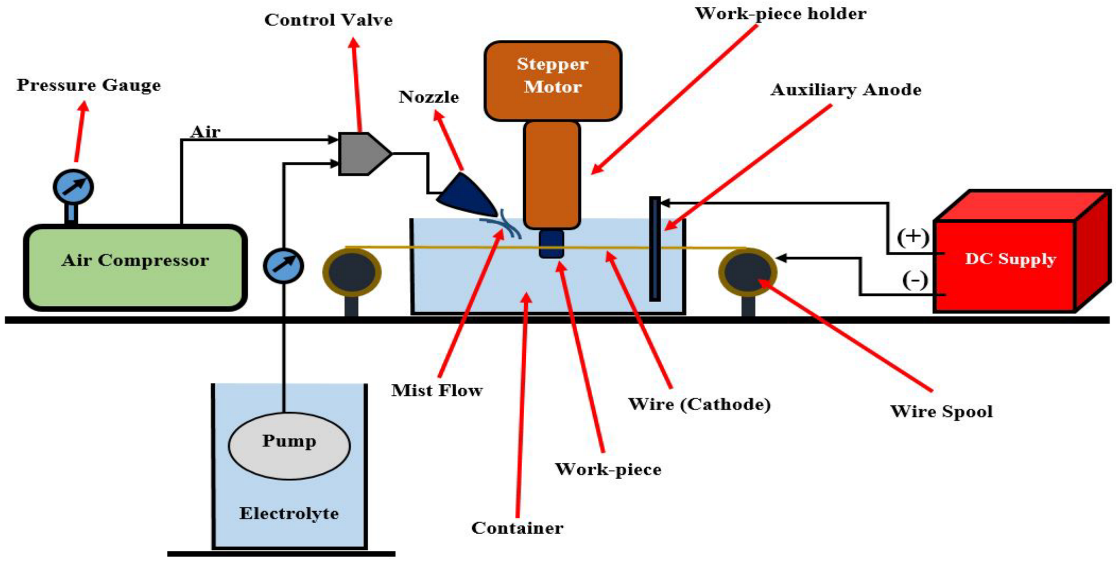

Fig. 2 Schematic WECDM setup

Fig. 3 Mist flow aided WECDM setup

Doloi *et al.,* [11] investigated zirconium oxide and silicon nitride ceramics. They examined the effects of machining parameters such as voltage, electrolyte concentration, and inter-electrode gap (IEG) on quality attributes, including MRR and radial overcut (ROC), in the ECDM process using KOH as the electrolyte. Among the process parameters, IEG was found to have the least effect on MRR. Aragonez *et al.,* [12] reported that digital dentistry is replacing manual procedures for dental restorations. Vat photopolymerization can produce ceramic restorations with high precision. The machinability of lithium disilicate glass ceramics was the focus of the study by Xiao-Fei Song *et al.,* [13], who evaluated the dental adjustment procedure using a handpiece and diamond burs. Jurado *et al.,* [14] found that ceramic and composite polishing systems significantly improved surface smoothness, recommending ceramic polishing systems for greater effectiveness. Bilal *et al.,* [15] provided a summary of theoretical and experimental studies on the EDM of ceramics, highlighting advancements in the EDM process. Mohammed A.'s 2015 research revealed that silane treatment enhanced the bond strength of lithium disilicate.

II. LITHIUM DISILICATE MATERIAL

The remarkable properties and versatility of lithium disilicate make it the material of choice for modern prosthetic dentistry, offering high aesthetic and mechanical performance combined with a minimally invasive approach. Lithium disilicate ceramics exhibit higher strength (approximately 360-400 MPa) compared to metal ceramics (approximately 80-100 MPa).

During our experimentation and study, we used lithium disilicate press ingot as the work material, with its properties shown in the table below.

TABLE I PROPERTIES OF WORKPIECE

Parameters	Values
Size	12.5 × 10 mm^3
Weight	2.97-3.01 g
Density	2.48 g/cm^3
Flexural Strength	320 MPa
Vickers Hardness	560 MPa
Pressurized Temperature	915-920 ^0C

III. RESULTS AND DISCUSSION

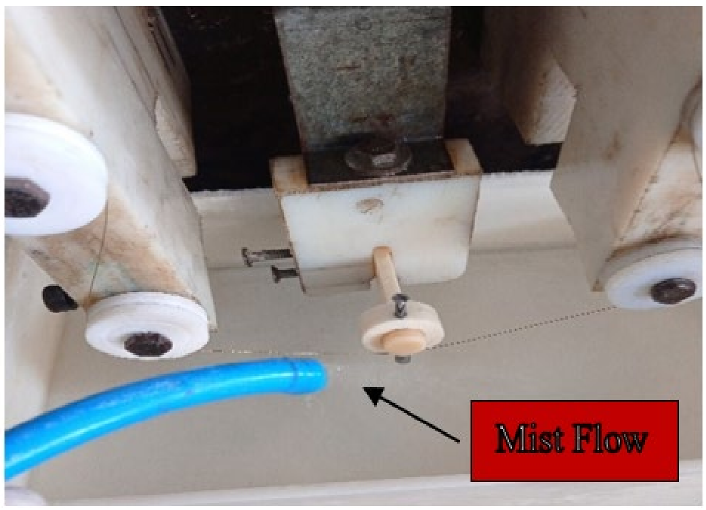

Fig. 4 Mist flow aided machining

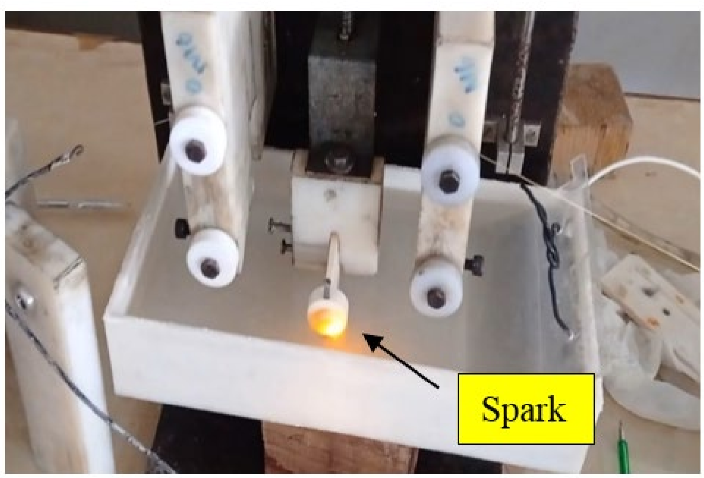

Fig. 5 Machining

Figure 4 shows mist flow-aided machining on the workpiece, while Figure 5 represents spark generation around the workpiece and the minimal material removal possible due to melting. During the study, we observed that machining this type of material is not feasible using the W-ECDM process because of the nature of the workpiece material (Table I indicates the material composition). As shown in the trial experiment images, experiments conducted with mist flow-aided and normal machining resulted in spark generation at 45 V, but deeper penetration into the workpiece was not achievable due to the material properties. Additionally, we conducted several experiments at voltages between 60-80 V for approximately 18-25 minutes. However, machining could not be performed on the lithium disilicate material, and wire breakage occurred due to the extended machining time on the workpiece.

After the experiments, the workpiece was examined using a Stereo-Zoom Microscope (SZM). Figure 6 shows the microscopic image, and Figure 7 indicates the depth of cut on the workpiece.

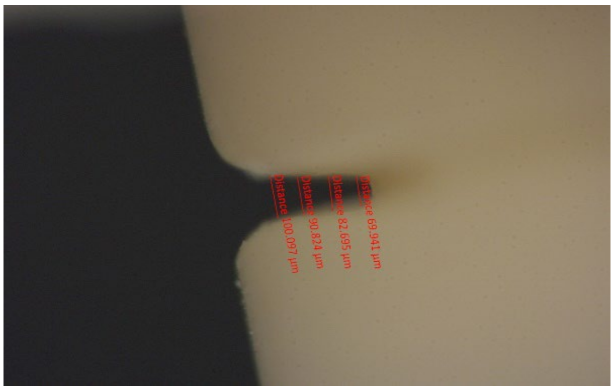

Fig. 6 Microscopic image of workpiece

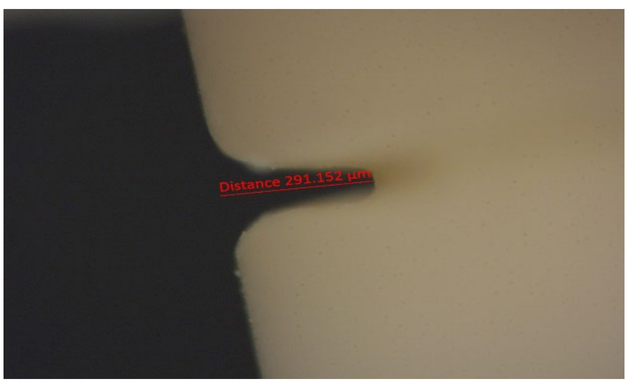

Fig. 7 Microscopic image shows DOC

IV. CONCLUSION

The study highlights the significant challenges faced in slicing lithium disilicate material using the wire-ECDM (Electrochemical Discharge Machining) process for dental applications. Along with the inherent difficulty of working with this material due to its hardness and brittle nature, special attention is required for cutting parameters to avoid distortion or damage to the material. These challenges are not solely technical in nature; they have far-reaching implications for dental applications, where accuracy and material integrity are crucial. By addressing these difficulties and potential pitfalls, this paper contributes to the scientific discussion on lithium disilicate in dental materials. This research provides valuable insights into these challenges, offering potential avenues for innovation to improve the properties and performance outcomes of lithium disilicate ceramic materials.

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