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A Study on Hybrid WECSM Setup During Cutting of E-Glass Fibre Epoxy Composite

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***Abstract* - Some of the well known non-conventional machining processes like electrical discharge machining (EDM), wire electrical discharge machining (WEDM) etc. are not suitable for machining of electrically nonconductive ceramic materials. E-glass fibre epoxy composite is a nonconductive ceramic material hence it is difficult to machine by the above mentioned machining processes. However, this material can be machined with conventional machining but compromise with accuracy, surface texture and micro cutting. Keeping in view, a hybrid machining setup is designed and fabricated based on the combined of both electro chemical machining (ECM) and WEDM technique. The fabricated wire electrochemical spark machining (WECSM) setup is utilized to machine e-glass fibre epoxy composite. This paper presents the results during machining of e-glass fibre epoxy composite on fabricated WECSM setup. The effect of different parameters of developed WECSM setup on machining performance characteristics such as material removal and spark gap width have been explain through various graphs. Test results and thereafter analysis show that the DC supply voltage and electrolyte concentration are most significant parameters on material removal and spark gap width. This practical research analysis on developed WECSM setup will provide new guidelines to the modern researchers and manufacturing engineers.**

***Keywords:* Hybrid machining, WECSM, e-glass fibre epoxy composite, Micro slicing.**

I. Introduction

Development in today's materials technology need appropriate processes for machining of low machinability materials. Non conventional machining processes are being effectively used in industries for production of components made of low machinability and electrically conducting materials. Advanced materials like glass fibre composites, ceramics etc. possess good strength, light weight, flexibility in shape and sizes, good corrosion and creep resistance, high thermal shock resistance etc. over monolithic metals. Even advanced fibre glass reinforced composite materials can be used against steel. The e-glass fibre epoxy composite materials has a wide range of application due to their high performance properties particularly in the corrosive areas such as chemical storage and processing, water and wastewater storage or processing, aeronautical and defense, building construction, electrical and electrical utility, marine industry etc.

Keeping in view, it is essential to develop an efficient and accurate machining method for processing of e-glass fibre epoxy composite materials. For effective machining of non-conductive e-glass fibre epoxy composite materials Wire Electro Chemical Spark Machining (WECSM) setup has been designed and fabricated. The fabricated WECSM Setup has been utilized to machine e-glass fibre materials and analyzes the effect of various parameters of the developed WECSM setup on the machining performance characteristics via different graphs. In the WECSM process, the material removal takes place due to the combined effects of electrochemical (EC) reaction and electrical spark discharge (ESD) action. It has two electrodes dipped in an electrolyte. The material to be machined is dipped in the electrolyte and placed very near to the cathode i.e. brass wire electrode used for this experimental investigation. A constant DC voltage is applied between the wire tool cathode and the counter electrode i.e. auxiliary anode. The counter electrode used is a flat plate made of copper of size 100 x 80 x 2 mm thick. When the applied voltage above a certain range hydrogen gas bubbles are formed at cathode (i.e. brass wire) and oxygen bubbles at the counter electrode (i.e. auxiliary anode). It has been observed that if the two electrodes are of different sizes then beyond a certain value of applied voltage, electric sparks appear at the electrode-electrolyte interface on the smaller electrode and the cell current drops. As voltage is increased, current density rapidly increases too. The density and the mean radius of the bubbles increase and bubbles finally coalesce into a gas film around the tool-electrode. Two anodes i.e. auxiliary anode and nonconductive work-piece dipped into an electrolyte are supplied to a constant DC voltage. A brass wire is traveling continuously and functioning as an electrode during machining operation.

From the review of literature, it is found that few research publications on electrochemical discharge machining and traveling wire electrochemical spark machining are available which are not sufficient to overcome the machining barrier from non conductive material machining, hence it demands a lot of applied research to explore the successful utilizations of the process in the machining area of nonconductive materials. Some of the available published research are reviewed and listed in this paper. Basak and Ghosh concluded that a substantial increase in the material removal rate can be achieved due to the additional inductance introduced [1]. Gautam and Jain investigated on electro chemical spark discharge machining process using various tool kinematics to enhancing the process capabilities [2]. Authors also studied the geometrical parameters and surface integrity of the machined specimens. Jain, et al. concluded that electrochemical spark machining with abrasive cutting tools gave the improved performance related to machining of electrically non conducting materials, alumina and borosilicate glass [3]. Kulkarni, *et al.* conducted an experimental study of discharge mechanism in electrochemical discharge machining. In the particular study, authors have attempted to identify the mechanism through experimental observations of time-varying current in the circuit. Based on these observations the basic mechanism of temperature rise and material removal was proposed [4]. Mediliyegedara, *et al.* studied and analyzed the electro chemical discharge machining (ECDM) process and concluded that ECDM process has advantageous over ECM or EDM because of higher machining rate [5]. Manna and Bhattacharyya studied a dual response approach for parametric optimization of CNC wire cut EDM during machining of particulate reinforced aluminium silicon carbide metal matrix composite (PRAl/SiC-MMC) [6]. Authors used Taguchi method for experimental design and the significant factors were identified for machining performance characteristics during WEDM of PRAl/SiC-MMC. Sen and Shan reviewed of electro chemical micro-to-micro-hole drilling processes [7]. Authors concluded that advanced hole-drilling process like jet-electrochemical drilling can be accepted in producing large number of quality holes in difficult to machined materials. Different authors [8-12] performed experiments on electrochemical spark machining process; they explained the effects of various parameters on response characteristics.

II. Planning for Experimentation

A wire electro chemical spark discharge machining (WECSM) setup has been designed and fabricated for experimental investigation. Different micro cutting tests are performed on electrically nonconductive high corrosive resistant and light weight material e.g. e-glass fibre epoxy composite on fabricated WECSM setup. Table I represents the detail of the developed WECSM setup, tool (wire electrode), work-piece and electrolyte used for experimentation. Material Removal (MR) is obtained by subtracting final weight from initial weight of work-piece. Contech Instrument Electronic Balance of resolution 0.1 mg is used to measure the weight of work-pieces before and after each run. Scanning Electron Micrograph (SEM) photographs are taken to analyze the surface texture of the machined surface. The micro slicing time is recorded by using a digital stop watch of accuracy 0.1s. The cutting time for a complete micro slice is calculated by difference between starting time and finishing time of each micro slicing operation.

Table I Details Of Experimental Conditions

Machine Used	Designed and Fabricated WECSM setup
Electrolyte used	Sodium Hydroxide (NaOH)
NaOH and natural water concentration	(i) 50 g/l; (ii) 100 g/l; (iii) 50 g/l; (iv) 200 g/l
Work-piece material	Electrically non-conductive e-glass fibre epoxy composite
Work-piece thickness	2 mm
Tool used	Brass wire of diameter 200 µm

III. RESULTS AND DISCUSSIONS

A series of experiments has been carried out with variation of different parametric setting value and the results are presented for discussion. Different graphs have been plotted to analyze the effect of various parameters of traveling-wire electrochemical spark machining (WECSM) setup on the machining characteristics e.g. material removal, spark gap width. Different scanning electron micrographs (SEM) show the characteristics of the generated spark gap width during WECSM operation.

A. Effect of Parameters on Material Removal

Fig.1 shows the effect of DC supply voltage on MR (MR, mg) during slicing of e-glass fibre epoxy composite on fabricated WECSM setup. From Fig.1, it is clear that the material removal (MR, mg) increases with increase of supply DC voltage. It may be due to the increase of potential difference between the tool (i.e. cathode) and anode (i.e. auxiliary anode) which may discharge or liberates more numbers of electrons per unit area of cathode and simultaneously act for making crater with dissolution of non-conductive anode i.e. work-piece. Maximum material removal is observed at 80V DC supply voltage. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 100 *g/l* electrolyte concentration, 0.15 *m/min* wire speed, 110 *mm* gap between tool (i.e. cathode) and auxiliary anode, 1.4 *amp* supply current with variation of supply DC voltage from 40 V to 80 V.

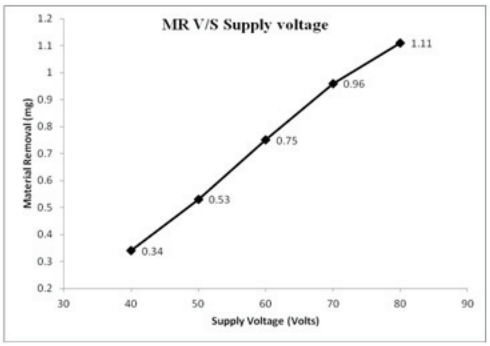

Fig.1 Effect of DC supply voltage on MR (MR, mg)

Fig. 2 shows the effect of electrolyte concentration on material removal (MR, mg). From Fig. 2, it is clear that the material removal (MR, mg) increases with increase of electrolyte concentration. Electrolyte concentration has great impact on the material removal. It may be due to the increase of charge carriers in the electrolytic solution as electrolyte concentration increases, which may discharges more numbers of ions per unit area of cathode. It may creating crater with dissolution of non-conductive anode i.e. work-piece. Maximum material removal is observed at 250 *g/l* electrolyte concentration. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for

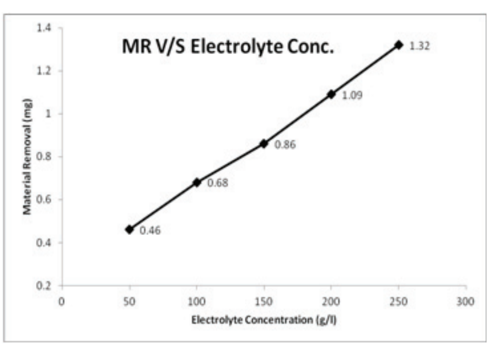

Fig. 2 Effect of Electrolyte concentration on MR

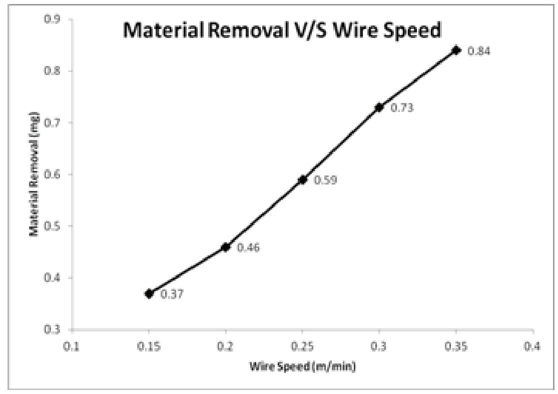

Fig. 3 Effect of wire speed on MR

continuous 90 *min* machining and at constant 40V supply voltage, 0.15 *m/min* wire speed, 110 *mm* gap between tool and anode and 1.4 *amp* supply current with variation of electrolyte concentration from 50 *g/l* to 250 *g/l*.

Fig. 3 shows the effect of wire speed on material removal (MR, mg). From Fig. 3, it is clear that the material removal (MR, mg) increases with increase of wire speed. Wire speed has smaller effect on material removal. It may be due to traveling of fresh wire coming quickly across the cutting zone and this may cause of higher number of spark discharge which helps to form more crater per unit time that's why the material removal is increases as increase the wire speed. Maximum material removal is observed at 0.35 m/min of wire speed. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 100 g/l electrolyte concentration, 110 *mm* gap between tool and anode and 1.4*A* supply current with variation of wire speed from 0.15 *m/min* to 0.35 *m/min*.

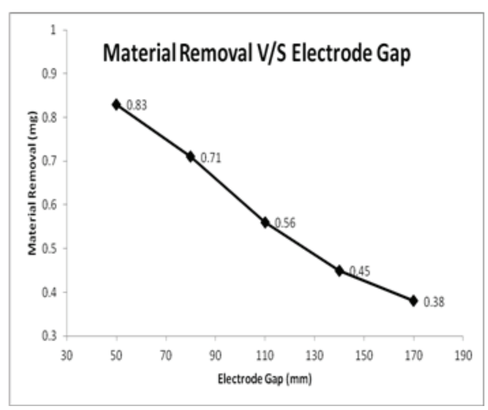

Fig. 4 Effect of gap between tool and anode on MR

Fig. 4 shows the effect of electrode gap on material removal (MR, mg). From Fig. 4, it is clear that the material removal

(MR, mg) decreases with increase of gap between tool and auxiliary anode. It may be due to the charge carriers have to travelling more paths so material removal is decreased. Maximum material removal is observed at 50 mm of gap between tool and auxiliary anode. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 100 g/l electrolyte concentration, 0.15 *m/min* wire speed and 1.4*A* supply current with variation of gap between tool and auxiliary anode from 50 mm to 170 mm.

Fig. 5 shows the effect of supply current on material removal (MR, mg). From Fig. 5, it is clear that the material removal (MR, mg) is increases with increase in supply current. Maximum material removal is observed at 2.2*A* of supply current. It may be due to as we increase the supply current the charge density increases which increases the formation of caters around the tool which blast continuously and work-piece material dissolve more in solution. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 100 g/l electrolyte concentration, 0.15 *m/min* wire speed, 110 mm of gap between tool and auxiliary anode and variation of supply current from 1.4 to 2.2*A*.

B. Effect of Parameters on Spark Gap Width

Fig.6 shows the effect of supply voltage on spark gap width (Wg, μm). Fig. 6 represents a curve showing the investigated results obtained during slicing of e-glass fibre epoxy composite is an electrically non-conductive high corrosive resistant, less weight, high strength and high temperature resistant material on developed TWECSM setup. From Fig.6, it is clear that the spark gap width (Wg, μm) increases with increase of supply DC voltage. It may be due to the increase of potential difference between the tool (i.e. cathode) and anode (i.e. auxiliary anode) which may discharge or liberates more numbers of electrons per unit area of cathode and simultaneously act for making crater with dissolution of non-conductive anode i.e. work-piece. Maximum spark gap width is observed at 80*V* DC supply voltage. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 100 *g/l* electrolyte concentration, 0.15 *m/min* wire speed, 110 *mm* gap between tool (.e. cathode) and auxiliary anode, 1.4*A* supply current with variation of supply DC voltage from 40 to 80*V*.

Fig. 7 shows the effect of electrolyte concentration on spark gap width (Wg, μm). From Fig. 7, it is clear that the spark gap width (Wg, μm) increases with increase of electrolyte concentration. Electrolyte concentration has significant effect on spark gap width. It may be due to the increase of charge carriers in the electrolytic solution due to increase in electrolyte concentration which may discharge

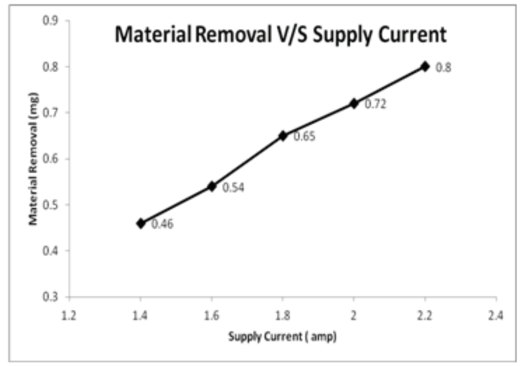

Fig. 5 Effect of supply current on MR

or liberates more numbers of ions per unit area of cathode and simultaneously act for making crater with dissolution of non-conductive anode i.e. work-piece. Maximum material removal is observed at 250 *g/l* electrolyte concentration. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 15 *m/min* wire speed, 110 *mm* gap between tool and anode and 1.4*A* supply current with variation of electrolyte concentration from 50 to 250 *g/l*.

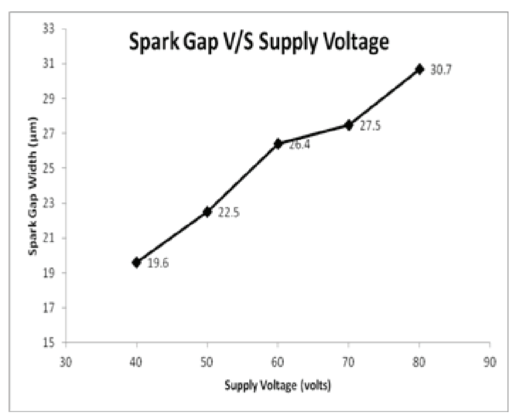

Fig. 6 Effect of DC voltage supply on spark gap width

Fig. 8 shows the effect of wire speed on spark gap width (Wg, μm). From Fig. 8, it is clear that the spark gap width (Wg, μm) increases with increase of wire speed. Wire speed has smaller effect on low speed but as speed increases the effect intensity also increases. It may be due to fresh wire coming quickly across the slicing of e-glass fibre epoxy composite and it may discharge stronger spark which helps to broken the gas bubbles and formation of more number of crater per unit time that's why the material removal is increases as we increase the wire speed. Maximum material removal is observed at 0.35 m/min of wire speed. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 100 g/l electrolyte concentration, 110 *mm* gap between tool and anode and 1.4*A* supply current with variation of wire speed from 0.15 to 0.35 *m/min*.

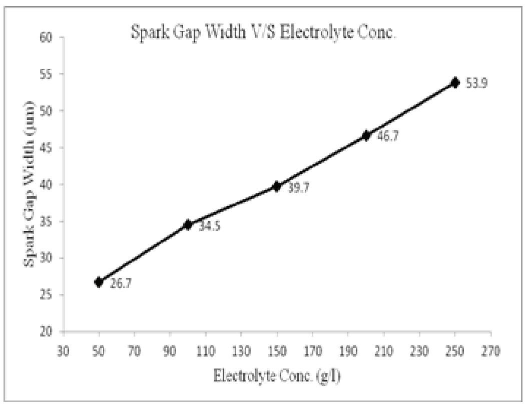

Fig. 7 Effect of Electrolyte conc. on spark gap width

Fig. 9 shows the effect of gap between tool and anode on spark gap width (Wg, μm). From Fig. 9, it is clear that the spark gap width (Wg, μm) decreases with increase of gap between tool and auxiliary anode. It may be due to the charge carriers have to travelling larger path so spark gap width is decreased. Maximum spark gap width is observed at 50 mm of gap between tool and auxiliary anode. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 100 g/l electrolyte concentration, 0.15 *m/min* wire speed and 1.4*A* supply current with variation of gap between tool and auxiliary anode from 50 to 170 mm.

Fig.10 shows the effect of supply current on spark gap width (Wg, μm). From Fig. 10, it is clear that the spark gap width (Wg, μm) is increases with increase in supply current. Maximum spark gap width is observed at 2.2 mm of supply current. It may be due to as we increase the supply current the charge density increases which increases the formation of caters around the tool which blast continuously and work-piece material dissolve more in solution. This graph is plotted on the results obtained during slicing of e-glass fibre epoxy composite for continuous 90 *min* machining and at constant 40*V* supply voltage, 100 g/l electrolyte concentration, 0.15 *m/min* wire speed, 110 mm of gap between tool and auxiliary anode and variation of supply current from 1.4 to 2.2*A*.

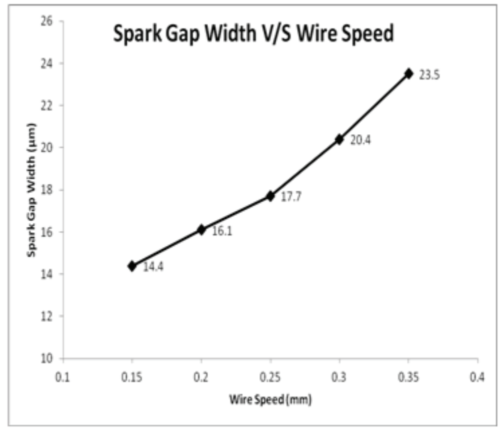

Fig. 8 Effect of wire speed on spark gap width

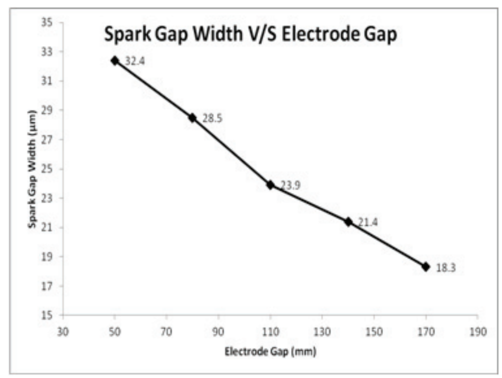

Fig. 9 Effect of gap b/w tool and anode on Wg, (μm)

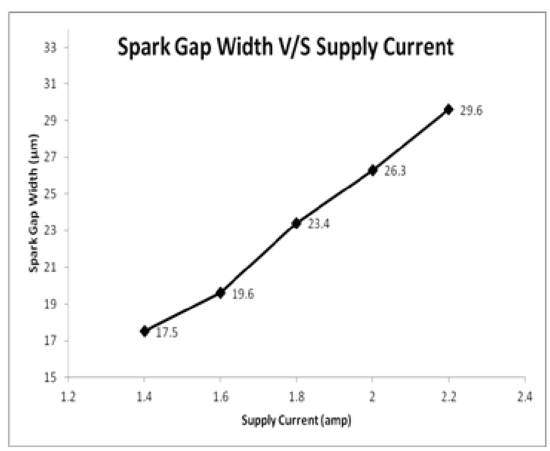

Fig.10 Effect of supply current on spark gap width

Fig. 11 shows a Scanning Electron Micrograph (SEM) of a micro slice section of e-glass fibre epoxy composite work-piece by wire electro chemical spark machining (WECSM) setup. The SEM graph shows the actual condition of the micro cutting surface. The SEM photo is an experimental result with parameters setting at 70*V* D.C supply voltage, 200 *g/l* electrolyte concentration, 0.15 *m/min* wire speed, 110 *mm* gap between anode and cathode and 1.6*A* supply current. The micro slicing shown in Fig. 11 is the result of continuous 30 minutes machining with 200 µm diameter brass wire electrode at 0.15 m/min cutting speed. The surface finish is very poor its may be due to high DC supply voltage and electrolyte concentration. This may also due to not proper flashing of electrolyte during machining and hence fibres and fins are remaining as it is at the micro slice part on e-glass fibre epoxy composite work-piece.

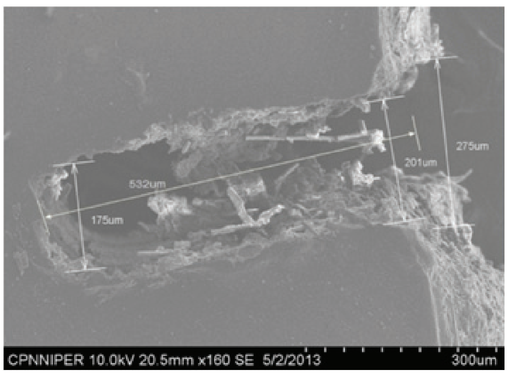

Fig.11 SEM of a slicing work-piece of e-glass fibre epoxy composite using 200 µm brass wire

IV. CONCLUSION

Based on the experimental results during slicing of electrically non-conductive high strength, wear resistance e-glass fibre epoxy composite on fabricated wire electro chemical spark machining (WECSM) setup and thereafter discussion on the investigated results the following conclusions are drawn as listed below.

(i) The developed WECSM setup can be effectively used for machining of non conductive e-glass fibre epoxy composite.

(ii) From SEM graph, it is concluded that at the beginning of micro cutting the width of the micro slice is slightly more than the wire diameter but after few minutes of cutting the width of the micro slice increases along the depth of cut. The surface of the micro slicing is irregular and poor surface. Uniform feed is an important for effective machining and controlling the uniform spark gap.

(iii) Many fins and scattered along the cutting surfaces are observed that may be due to the adhering of small particles scattered from the work-piece surface during cutting due to improper and insufficient flow rate of electrolyte during machining. The burrs are also noticed along the surface of micro cutting.

From the above mentioned points, it is clear that micro slicing is possible but for generation of high surface texture may required parametric optimization.

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