State of the Art on Laser Assisted Electrochemical Machining

Indranil Mandal* and B Doloi
Production Engineering Dept., Jadavpur University, Kolkata, India
*mandal.indranil2@gmail.com

Abstract. Laser Assisted Electrochemical Machining (LAECM) has proven its advantages and applications over almost all the range of conductive materials. It offers its adroitness to generate simple shapes to complex shapes from macro to micro machining. Laser assisted ECM is a hybrid approach of machining which has been manifested to obtain improved results in terms of surface integrity, thermal damage, geometrical tolerance and material removal rate. Laser assisted Electrochemical Machining (LAECM) is a hybrid machining process in which laser enhances the electrochemical dissolution process by increasing the temperature and hence the current density of the electrolyte. Laser helps to remove material from the particular machining zone and stray machining effect is reduced and thus improves the precision and efficiency of LAECM, also productivity. New route of laser assisted hybrid machining processes has been built in the past decade by few of the researchers to reduce the intrinsic problems of ECM. This paper reviews on the investigation into LAECM process. The article also highlights various possibilities and applications of LAECM process. There are various challenges in LAECM process which have been also discussed in this paper.

1. Introduction

Hybrid machining process has been developed by combining two or more processes to take the advantages and also to overcome the problems of individual processes. Hybrid process is more advantageous in every aspect than a single machining process. Imperative role is played by the advanced material in modern fabricating industries like automotive, aerospace, and tool and die manufacturing industries. HMP’S are accomplished to encounter the requirements of ultra precision machining. It also meets the high productivity requirements along with dimensional tolerance and surface quality for manufacturing of various advanced components [1].

Laser assisted machining is one of the heat-assisted paramount category of HMPs, in which the energy of laser beam is utilized to soften the work material during traditional machining, i.e. milling and turning. Beside that in ECM process the application of laser beam is a well-ordered way for increasing the temperature of the machining zone and thus the assistance of laser enhances the electrochemical dissolution rate.

Classifications of Laser-assisted HMPs are as follow:

a. Laser Assisted Mechanical Machining Processes: During conventional machining processes i.e. milling, grinding, turning etc. the job material is heated ahead the cutting tool with the help of laser. Laser beam softens the material before conventional machining.

b. Laser Assisted Advanced Machining Processes: The energy of laser beam assists the material removal in Advanced Machining Processes (AMPs) [2].
2. Laser Assisted Electrochemical Machining (LAECM) Process

In laser assisted electrochemical machining process (LAECM) laser beam is utilized to enhance the machining rate and accuracy of Electrochemical Machining process. The fundamentals of laser assisted ECM are discussed herein after.

2.1 Fundamentals of Electrochemical Machining (ECM)

In ECM process material removal takes place due to chemical dissolution of electrolyte. The main advantages of ECM include machining of almost all conductive materials with better surface finish, does not apply any stress in the workpiece and no tool wear. Due to stray machining effect the precision and accuracy of ECM are decreased. So this effect must be controlled by removal of material from specific machining zone to get better precision and accuracy. ECM is applied in various fields such as aerospace, medical industries, defence etc.

2.2. Lasers Used in LAECM Process

In LAECM laser improves localization of the dissolution process by increasing the temperature of electrolyte and increases MRR, precision and accuracy. Most widely used types of laser in LAECM are low power (375 mw-570 mw) Nd: YAG lasers and fiber lasers etc [4]. The laser is a non-contact thermal energy technology and it is also used in material processing. For the heating and preheating of various materials the laser heat source can be used.

2.3. Fundamentals of Laser Assisted ECM Process

Due to stray machining effect the precision and accuracy of Electrochemical Machining process are decreased. Another drawback in ECM includes complex tool design. LAECM eliminates this problem by focusing laser in the machining zone. Laser assists the ECM process. Hence the accuracy and precision of LAECM process are increased [7].

Laser assisted Electrochemical Machining (LAECM) is a hybrid machining process in which laser beam assists the ECM process and increases its machining performance by increasing the temperature of electrolyte which further increases its current density. The laser by its thermal activation assists dissolution and laser doesn’t remove any material.

The main tasks of the laser beam in LAECM are as follows: i. According to the Arrhenius law the rate of dissolution is increased by raising the temperature of the electrolyte in the inter electrode gap ii. The temperature of electrolyte is to be increased for getting higher current density and conductivity. iii. Surface passivation is eliminated, which increases the material removal rate intensification. Thus stray machining effect can be reduced by focusing the laser in particular machining zone [4]. In the machining zone the temperature is raised with the help of laser beam. This effect has a positive effect on treatment by increasing electrolyte conductivity hence current density, the ECM reactions are initiated easier, and transportation of the removed material and the diffusion of ions are intensified to enhance the machining precision.

3. Research Status on Laser Assisted Electrochemical Machining (LAECM) Process

Research work on laser assisted electrochemical machining (LAECM) has been performed by various researchers and some of the important work has been highlighted in this present paper.

Applications of individual advanced machining processes are limited in some areas such as machining of advanced and difficult to cut materials, requirements of ultra precision machining etc. Hybrid machining processes reduce these problems in which one process energy assists the main process energy for obtaining better material removal rate. Thus precision and accuracy of main
process are increased. Machining of novel materials and various complex shapes can be obtained by hybrid processes. In LAECM process laser assists the electrochemical process and increases the temperature and current density of electrolyte and improves machining performance. For obtaining high level of localization in machining diode pumped solid state pulse laser can be applied [1, 2, 4, 8].

In laser assisted ECM laser energy and ion energy together are used for machining conductive materials from particular machining zone and stray machining effect is reduced. Various novel materials can be machined by LAECM process and laser helps in removal of passivating layer in ECM process [3]. LAECM process can be applied for machining of steels, titanium alloys and super alloys. Micro dimensional features can be fabricated by LAECM process [3].

In LAECM process laser increases the chemical dissolution and hence accuracy is increased. Green laser of wavelength 470-560 nm can be applied for low absorption coefficient electrolyte in ECM process. A mathematical model has been developed for the selection of laser radiation intensity. Laser enhanced electrochemical machining process can be applied in various engineering fields such as biomedical etc. LAECM process can be also applied for surface structuring of workpiece [5].

Point-by-point and scan methods are two main LAECM methods. Better etching surface quality can be achieved by scan method and various complex profiles can be made by this method. LAECM process has various advantages such as better machining efficiency, removal of passivating layer, lesser HAZ etc. Complex microstructures and integrated structures can be made by this method [6].

In LAECM laser enhances chemical dissolution process by increasing the current density of electrolyte. LAECM process can be applied for machining of difficult to cut conductive materials. LAECM improves machining performance and also accuracy of ECM process [7].

Silicon nitride ceramics and metallic alloys can be machined by laser assisted machining. Higher material removal rate can be achieved by hybrid machining process [9].

In LAECM laser reduces activation energy level and increases the temperature of electrolyte. The current density of electrolyte is increased and hence chemical dissolution process is increased. Thus higher material removal rate can be obtained [10].

Conductive materials can be machined by Jet Electrochemical Machining (JECM) process and effect of stray machining affects this machining by reducing the effectiveness. Hybrid Laser Assisted Jet Electrochemical Machining (LAJECM) process can eliminate this problem and material removal occurs from particular machining zone due to the metal dissolution by electrochemical action that follows the main principle of Faraday’s laws of electrolysis. Laser beam assists the ECM process and increases its machining performance by increasing the temperature of electrolyte which further increases its current density. Laser assistance increases accuracy and precision of LAJECM process. If supply voltage, duty cycle and electrolyte concentration are increasing MRR and taper are also increasing. The main significant parameters are supply voltage and inter electrode gap for MRR and electrolyte concentration and supply voltage for taper [11].

4. Challenges in LAECM process

The wavelength of laser radiation should be properly selected so that the electrolyte layer should absorb minimal energy and for this reason the electrolyte layer should be as thin as possible. In LAECM, one of the challenges is to investigate the effect of laser radiation on the current efficiency of the anodic dissolution which is not still properly understood. In LAECM, shaping of small elements (5-500 µm) with high accuracy (1-10 µm) that are made from difficult-to-machine materials such as ceramics, composites and alloys is also a challenging area. Another challenging area in LAECM is to minimize the formation of high-absorptive layer of dissolution products.
5. Experimental Set-up of LAECM

The schematic diagram of Laser Assisted Electrochemical Machining set-up is shown in Figure 1. It describes LAECM set-up where laser is focused in the machining zone from the side of the electrode.

A low power laser beam is focused through reflector, focusing lens and polarizer to the specific machining zone during LAECM process. Laser strikes the workpiece and due to absorption of laser energy the temperature of material raises and heats up the adjacent electrolyte, which increases the rate of electrochemical reactions and enhances material removal rate. Electrolyte is supplied through pump to the machining zone. X and Y axis are controlled by servo motor and Z axis is controlled by stepper motor for tool feeding system.

![Figure 1. Schematic diagram of the experimental set-up of LAECM.](image)

6. Various possibilities and applications of LAECM process

The laser hybridized with ECM process improves surface finish, removes thermal defects and increases precision and accuracy of ECM process. Laser enhances electrochemical dissolution by increasing the temperature of electrolyte and hence current density. LAECM process can be applied for machining of aluminium, titanium alloy, stainless steel etc. LAECM process can be applied for surface structuring and various micro-dimensional features can be manufactured [3].

7. Conclusions

The effect of hybrid machining processes has greater influence than the sum of the advantages of a single machining process. Application of laser based hybrid machining processes is recently increasing in various industries.

Laser assisted Electrochemical Machining (LAECM) method combines two different sources of energy at the same time: ions energy and photons energy. Laser has been used to improve localization of the dissolution phenomena in electrochemical machining process. Surface layer as well as the machined surface of the job material undergoes through several chemical and physical
phenomena due to the heat generated by laser. Faster chemical dissolution is achieved by the interaction of laser as it intensifies the kinetics of the chemical reactions.

LAECM process enhances precision, accuracy and surface finish of ECM process and also reduces thermal defects. LAECM process can be applied for machining of hastelloy, titanium alloy, stainless steel, and aluminum materials. LAECM has potential applications to fabricate micro-cavities and micro-structures cavities of different size and shapes needed for electronics, bio-medical, aviation and optical industries etc. Further investigations can be done on LAECM by studying the several process parameters that affect the performance of LAECM process, minimization of stray current of ECM by laser assistance and comparative study between LAECM and Jet Electrochemical Machining (JECM) process.

References

[1] Saxena KK, Bellotti M, Qian J, Reynaerts D, Lauwers B and Luo X 2018 Overview of Machining Processes chapter 2 pp 21-41
[2] Gupta K, Jain NK, Laubscher RF 2016 Hybrid Machining Processes perspective on Machining and Finishing ISBN 978-3-319-25920-8 PP 45-58
[3] Saxena KK, Bellotti M, Camp DC, Qian J and Reynaerts D 2018 Electrochemical Based Hybrid Machining Chapter 5 pp 111-129
[4] Wyszynski D, Skoczypiec S, Grabowski M, Ruszaj A and Lipiec P 2012 Electrochemical Microprocessing Assisted by Diode Pumped Solid State Nd:YAG Pulse Laser Journal of Machine Engineering 12 pp 131-142
[5] Skoczypiec S 2015 Application of laser and electrochemical interaction in sequential and hybrid micromachining processes Bulletin of the polish Academy of Sciences 63 pp 305-314
[6] Zhang Z, Cai M, Feng Q and Zeng Y 2014 Comparison of different laser-assisted electrochemical methods based on surface morphology characteristics The International Journal of Advanced Manufacturing Technology 71 pp 565-571
[7] Malik A and Manna A 2018 Multi-response optimization of laser-assisted jet electrochemical machining parameters based on gray relation analysis Journal of the Brazilian Society of Mechanical Sciences and Engineering 40 pp 1-21
[8] Lee CM, Woo WS, Kim DH, Oh WJ, and Oh NS 2016 Laser-Assisted Hybrid Processes: A Review International Journal of precision Engineering and Manufacturing 7 pp 257-267
[9] Chryssolouris G, Anifantis N and Karagiannis S 1997 Laser Assisted Machining An Overview Journal of Manufacturing Science and Engineering 119 pp 766-769
[10] Pajak P T, De silva AKM, Harrison DK and Mc geough JA 2006 Precision and efficiency of laser assisted jet electrochemical machining Precision Engineering 3 pp 288-298
[11] Malik A and Manna A 2018 Investigation on the laser-assisted jet electrochemical machining process for improvement in machining performance The International Journal of Advanced Manufacturing Technology 96 pp 3917-3932