

Introduction to Laser-Assisted Machining

Sandip Kumar^{1*}, K. Vijetha¹, Jagadeesha T.², Abhishek Ghosh³, S. Rama Sree⁴,
Prasenjit Chatterjee⁵, Sreenivasa Reddy Medapati¹ and Nabankur Mandal⁵

¹*Department of Mechanical Engineering, Aditya Engineering College,
Surampalem, India*

²*Department of Metallurgy and Materials Engineering, Indian Institute of
Engineering Science and Technology, Howrah, Shibpur, India*

³*Department of Mechanical Engineering, NIT Calicut, Kozhikode, India*

⁴*Department of Computer Science & Engineering, Aditya Engineering College,
Surampalem, India*

⁵*Department of Mechanical Engineering, MCKV Institute of Engineering,
Howrah, India*

Abstract

Due to their inherent physical–mechanical qualities, advanced materials such as Ti6Al4V, Inconel, and sophisticated technical materials like composites and ceramics are explored and utilized extensively in biomedicine, nuclear power, etc. However, machining is always involved in turning these novel materials into engineered goods. These substances are regarded as advanced materials due to their machinability features, which include greater machining temperature, reduced surface quality, and less tool life expectancy. These substances are proven to be economically unfeasible to machines using conventional techniques. Recently, there have been numerous attempts to use external energy-aided machining to better these materials' machinability. Scientists in the field of material removal mechanism have recently concentrated their attention on laser-assisted machining (LAM), one of the various externally aided machining methods. The aim of this research article is to explore and describe the prospective applications of LAM for advanced materials, as well as the advantages and drawbacks of this technology.

Keywords: Laser-assisted machining, advanced materials, laser parameters

*Corresponding author: sandip.sandip.kumar@gmail.com

1.1 Introduction

In the industrial sector, the usage of advanced materials including tool steels, semiconductors, biomaterials, and smart materials is rising [1]. To fulfill the growing demand for greater heat and strength resistance, particularly in the aerospace industry, they are still being investigated and developed [2, 3]. These cutting-edge materials are often machinable because of higher thermal stress of the machining zone. The materials are challenging to manufacture because of characteristics like higher thermal effect and large machining forces. Thus, an innovative approach known as thermally aided machining was established. Plasma-assisted machining, induction and furnace preheating method, and gas torch are a few examples [4].

Although hard-to-cut materials have good qualities, their physical and chemical traits make them challenging to manufacture with standard machinery [5]. A brand-new and cutting-edge method for machining materials with high wear resistance is called laser-assisted machining. For softening the material during the cutting time, the laser is employed as a heating resource with the laser beam directed on the unmachined portion of the job. Heat is added to the substance, softening the surface layer and causing ductile deformation as opposed to delicate deformation during machining [6]. The most significant benefit of laser-aided cutting is its ability to generate job surfaces that are considerably improved compared with those generated by traditional machining, along with a superior material removal rate and low tool erosion [7]. LAM is suitable due to its greater laser beam intensity at less beam power, good concentrating features brought on by extremely brief pulse duration, simplified manufacturing process, eco-friendliness, and improved surface finish [8].

For applications requiring high strength and heat resistance, including those in the aerospace, medical, and electronic industries, advanced materials have been developed in recent decades. These materials include ferrous alloys, cobalt–chromium alloys, and composites [9, 15]. These materials have significant corrosion resistance and the capacity to maintain superior strength at high temperatures. These materials outperform more traditional engineering materials in terms of strength and toughness. However, since converting a final component costs half of the product's final cost, applications of these materials are currently not expanding [9, 10]. Low cutting speed and reduced cut depth because of increased tool wear are to blame for this. As a result, these materials are regarded as being

tough to cut. Numerous issues arise during machining, including excessive heat creation during cutting time, a propensity for BUE creation, and catastrophic cutting tool failure [11–14]. Due to these machining processes, poor capability of machinability, higher capital cost, and low efficiency may be substantially affected. The intrinsic properties of hard-to-cut materials make traditional machining techniques like milling or turning ineffective. These materials are currently being machined using a variety of cutting-edge techniques, including electrochemical machining, plasma machining, and thermally aided machining techniques like laser machining. Due to its greater advantages, significant technological advancement, and commercial viability, laser-aided machining (LAM), one of the various techniques, is becoming more and more popular with advanced materials. The current state of LAM and its problems are highlighted in this research with respect to the impact of laser machining factors on the productivity of smart materials.

1.2 Laser-Assisted Machining—Overview

A high-power laser is utilized in laser-aided machining, a hybrid process, to heat the job before material removal using a traditional machine tool. The yield strength of fragile material drops down below its rupture strength at high temperatures, transforming the material's distortion behavior from fragile to ductile. Also, strong, ductile materials lose some of their yield strength at high temperatures, which lowers tool erosion and cutting ability while also enhancing surface quality.

Nd:YAG and CO₂ laser are two primary laser sources that are frequently utilized in LAM studies. The latter has superior absorptivity because it has a shorter wavelength. Because the CO₂ laser absorbs less laser energy than Nd:YAG, it is less effective in cutting the most advanced materials including titanium and composite materials. Most of the study has addressed the difficulties in traditional machining while concentrating on the advantages of LAM. However, the laser machining factors affect the LAM consequences. Feed rate, spot diameter, and cutting speed are the primary operational aspects associated with LAM. Due to the multiplicity of control factors and how they interact, finding the ideal LAM setting is challenging. Additionally, a numerical analysis based on experimental design is required to explore how the ideal LAM parameter affects other variables and how they interact. Figure 1.1 shows the schematic setup of LAM.

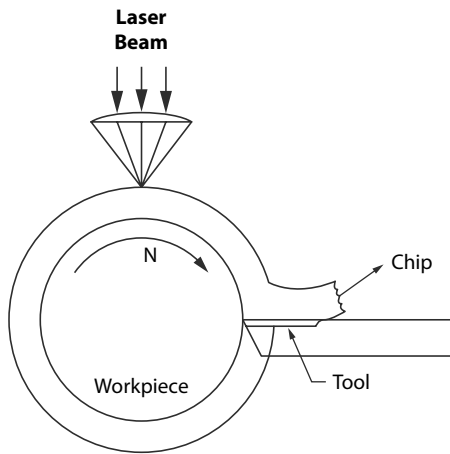


Figure 1.1 Schematic setup of LAM.

1.3 Machining of Advanced Materials

The adoption of advanced materials has accelerated with applications in automotive, shipbuilding, and semiconductors in recent years because they outperform standard metals in terms of high-temperature strength, durability, and corrosion resistance [16–19]. Titanium alloy [20], Inconel 718 alloy [21], compacted graphite iron [22], mullite [23], Si_3N_4 ceramic [24–26], Waspaloy [27], and A359 aluminum matrix [28] are a few examples of materials that are challenging to cut. Hard-to-cut materials also include magnesium AZ91 [29], stainless steel P550 [30], and AISI D2 steel [31].

1.3.1 Titanium Alloys

This is mainly because titanium alloys have properties like high creep, high wear resistance, fine biocompatibility, and high corrosion resistivity, which make them interesting materials in a variety of manufacturing areas like biomedical, nuclear, etc. Owing to their greater chemical attraction and less heat conductivity, titanium alloys are regarded as advanced materials. The tool life is decreased during the machining of titanium alloys.

S. Sun *et al.* [32] turned titanium alloy dry at various cutting speeds, feed rates, and cut depths to see how the repeated force frequency altered in relation to the cutting speed and feed rate. With greater cutting speed, the cutting force rises due to the strain rate hardening at higher and lower strain rates correspondingly. Outside of these cutting speed ranges, the

cutting force reduces with boosting cutting speed because of the thermal tempering of material. Some investigations on titanium alloys demonstrate that cryogenic machining outperforms dry machining in terms of tool life. The impact of cryogenic machining was examined by M.J. Bermingham *et al.* [33] using various combinations of feed rate and depth of cut at fixed material removal rate and cutting speed. In dry machining, the combination of lower cutting speed and higher depth of cut improved tool life 1.6 times more than the combined lower depth of cut and higher speed. Tool life at the specified machining conditions is 13 min for dry machining and 20 min for cryogenic machining. Hybrid machining and laser-aided machining (LAM) were utilized to enhance metal removal and tool life. Surface finish, microstructure, and tool wear are assessed as output parameters from the two processes. The input parameters for the two methods are tool material and material removal temperature. LAM enhanced the lifespan of the cutting tool more than 1.8 times compared with traditional machining for cutting speed below 1,120 m/min, whereas hybrid machining improved the lifespan of the tool more than 3 times for machining speed below 155 m/min at material removal temperature of 255°C. For identical machining circumstances, dry, laser-aided, and hybrid machining have tool lives of 28.62 min, 48.78 min, and 55.10 min, respectively. Using thermally assisted machining, M.J. Bermingham *et al.* [34] described the wear mechanism and tool lifespan for uninsulated carbide tools. By heating the job to 350°C, this technique minimizes the cutting forces by up to 35%. Rahman Rashid *et al.* [35] explored how the laser affected the cutting force and temperature studied at different cutting speeds and feed rates. Over the entire range of feed rates and cutting speeds, the cutting forces are lowered by 16%. The ideal feed rates for industrial applications are between 0.16 mm/rev and 0.26 mm/rev for a laser power of 1,205 W. Cutting energy is only slightly reduced below a feed rate of 0.16 mm/rev; however, erosion of the tool develops quickly above 0.26 mm/rev. The ideal cutting speed range for titanium alloy when using a 1,210-W laser is between 26 and 105 m/min. Below 30 m/min, high thermal energy induces chip tool welding, which compromises the machined quality of the surface, and beyond 105 m/min, tool erosion is maximized. To significantly reduce the cutting forces during the milling of titanium alloys using laser power, the temperature range should be between 1,055°C and 1,255°C.

1.3.2 Nickel-Based Alloys

Due to their benefits over titanium alloys, nickel-based alloys including Udimet and Waspaloy among others have gained popularity in gas turbine

and aerospace, owing to their wide operating temperature range in harsh environments. Improved hot strength, hardness, high melting temperature, high resistance to erosion, and resilience to thermal shock are just a few of the features that nickel-based alloys exhibit. Because of the great strength of nickel alloys, higher cutting forces and temperatures are generated during machining. Extreme tool erosion and poor machined quality are caused by a sharp rise in cutting temperature. Additionally, as the temperature drops below 650°C, nickel alloys become harder. These are referred to as tough-to-manufacture materials due to their poor surface polish, low cutting speeds, and limited tool life [15].

By assessing tool erosion, surface roughness, and cutting pressures, Mark Anderson *et al.* [21] assessed the machining capability of Inconel 718 under different conditions, i.e., feed rate and depth of cut. While the machining temperature rises from ambient temperature to 650°C, the explicit cutting energy reduces, the surface finish is improved, and the ceramic tool life exceeds traditional machining by 150%–250%. When cutting Inconel 718 at 4 m/s, the cost is reduced by 55% for traditional ceramic machining and 66% for traditional carbide machining. These are LAM's advantages. The laser-assisted machining of Inconel 718 with ceramic and carbide inserts was exhibited by G. Germain *et al.* in their publication [36]. Independent of the insert of the cutting tool, LAM drastically reduces the cutting pressures by about 42%. In contrast to traditional machining, LAM improves the tool lifespan of ceramic inserts by up to 26%. In LAM, carbide inserts have a shorter tool life than in traditional machining. Under laser-aided, dry conditions, H. Attia *et al.* [37] investigated the high-speed machining capability of superalloy Inconel 718. The tests were performed utilizing a ceramic cutting tool with Nd:YAG laser for feed up to 0.6 mm/rev and cutting speed up to 550 m/min. In comparison to traditional machining, the surface quality is enhanced by over 25%, the material removal capability was improved by about 850%, and the cutting forces were substantially lower at the ideal cutting circumstances. By assessing tool wear and surface finish, Hongtao Ding *et al.* [27] assess the machining capability of Waspaloy at different machining conditions, i.e., feed and cutting speed. For optimal cutting conditions while working with Waspaloy and WG-300 tools, the machining temperature range is 300°C to 400°C. In comparison to traditional machining, tool life is enhanced by 55% while using LAM. When the temperature is raised to 405°C during metal removal, there is a 21% decrease in cutting forces. For the same machining circumstances, the cutting forces for traditional machining and LAM are 200 N and 160 N correspondingly.

1.3.3 Ceramics

Sophisticated ceramics, i.e., alumina, zirconia, etc., are utilized for the fabrication of industrial components like rotors, artificial hip joints, etc. owing to their properties, i.e., high corrosion resistance, no wear, etc. Due to higher hardness and brittleness, the machining of ceramics is incredibly problematic. Diamond grinding is one of the machining methods to obtain precise components utilized in advanced fields. When the oxyacetylene flame is utilized as the heat source, mullite and Si_3N_4 undergo plastic deformation, whereas alumina and zirconia experience thermal fracture. This improves surface roughness and tool wear. Si_3N_4 LAM offers substantial benefits over traditional machining.

The output parameters, i.e., laser power and preheating time, are measured along with the performing qualities such as tool wear, metal removal mechanism, and surface quality. When compared with traditional machining, LAM improves tool life. Adhesion, the principal cause of tool wear, is reduced by keeping the machining zone at a temperature that facilitates quick material release. The thickness of grinding is more than the thickness of the LAM-affected layer of the job. On a machined surface, there is no chance of underlying cracks, and LAM material strength does not deteriorate. The evaluation of pressureless sintered mullite ceramics using LAM was published by Patrick A. Rebro *et al.* [38]. To achieve the best performance indicators, i.e., surface temperature and specific cutting energy, different machining conditions are decided from the input factors, i.e., depth of cut, beam diameter, and feed rate. A reduction in the precise cutting pressures, a sizable enhancement in the lifespan of a tool, and improved job surface qualities are all made possible by laser power levels between 170 and 190 W. The depth of incision should be about 0.75 mm to reduce thermal fractures. If there is sufficient laser energy absorption, the feed varies from 0.013 to 0.017 mm/rev to retain proper temperature gradients and prevent thermal rupture. The resulting extreme temperature gradients brought on by greater feed rates are what cause the thermal fracture of the job. When using a polycrystalline cubic boron nitride (PCBN) cutting tool, Frank E. Pfefferkorn *et al.* [39] studied the LAM of magnesia moderately stabilized zirconia (PSZ) to ascertain the impact of heating on performing measures like tool wear, surface integrity, and metal removal mechanism. By raising the material removal temperature from 530°C to 1,210°C, the specific cutting energy decreases from 6.7 to 2.7 J/mm³ and tool life improves from 2 to 122 min. Despite a significant decrease in material removal temperature, the specific cutting energy decreases with higher feed. For this matrix, temperatures between 900°C and 1,100°C are ideal

for material removal. Aluminum oxide (Al_2O_3) ceramic materials were subjected to laser-assisted machining tests under a variety of operating parameters, including depth of cut, pulsed frequency, and feed. Both surface finish and material removal are performance indicators. To achieve an appropriate surface finish, higher rotating speeds are necessary. When the temperature of the material being removed is more than 850°C , the laser power gives adequate energy to allow the workpiece to be easily machined and attain glass transition temperature.

1.3.4 Ferrous Alloys

Stainless steels and hardened steels are the categories of iron-based, advanced alloys utilized in automotive, food processing industries, and aerospace. Low carbon steels, in particular AISI 1008, have a problem during machining that results in continual coiled chips that can damage the surface being machined, jam an automated machine tool, and shut down the machine. Low carbon steels have a propensity to stick to the cutting tool and create built-up edges, which can have an impact on the surface finish and tool life of the machined surface. Due to their higher heat capacity and lower thermal conductivity, stainless steels are challenging to cut. When machining steels that are harder than 45 HRC, the term “hard machining” is used.

Utilizing a high-power laser in longitudinal and orthogonal turning procedures, the LAM of completely hardened AISI D2 tool steel is demonstrated. When compared with traditional machining, LAM eliminates catastrophic carbide cutting tool breakage, minimizes saw tooth chip formation, and nearly doubles tool life. Because of its limited power density, the high-power laser system is suitable for milling instead of turning. Surface roughness, cutting pressures, and tool erosion are assessed by adjusting material removal, depth of cut, and feed rate. In comparison to traditional machining at a feed rate of 0.3 mm/rev, the tool span is improved by 61% at a cutting speed of 1.8 m/s, feed rate of 0.17 mm/rev, and metal removal temperature of 402°C . At a feed rate of 0.155 mm/rev, surface quality is enhanced by 5.2% in comparison to traditional machining. Surface finish is $2.43\ \mu\text{m}$ for conventional machining and $2.26\ \mu\text{m}$ for LAM. Additionally, LAM lowers the cost of cutting an engine cylinder liner by about 25%. By adjusting the operating settings for the feed rate, cutting speed, and heating, the investigation is carried out utilizing laser-aided machining of an AISI 4130 shaft [40]. When compared with the traditional hard turning technique, the particular cutting energy and cutting force are lowered by 21% at a material removal temperature exceeding 200°C . In traditional

machining, the surface finish is $1.7\ \mu\text{m}$, whereas in LAM, it is between 0.3 and $0.5\ \mu\text{m}$ under similar cutting circumstances. The component's hardness following LAM is typically between 48 and 49.5 HRC, which is comparable to traditional machining. LAM generates a compressive surface axial residual stress that is roughly 155 MPa higher than traditional machining. LAM is utilized to machine high chromium white cast iron [41]. Surface profile, temperature, and hardness are all significantly influenced by laser power. LAM can only decrease the feed and cutting forces by a combined 25% and 23%, respectively.

1.3.5 Composites

Due to the existence of strong reinforcement fibers in a brittle matrix, composites typically have an inhomogeneous and anisotropic character. Uncut fibers, excessive dimensional deviation, and fiber pullout all contribute to poor surface quality. SiC, Al_2O_3 , and other hard abrasive particles included in the composite create a significant tool wear that is harder than that caused by WC tools. Metal matrix composites are advantageous for structural applications because of their high rigidity and strong damage resistance under a variety of operating situations [42]. Despite having outstanding performance, composites are difficult to machine, which results in significant tool erosion and trouble obtaining good surface quality [43].

The LAM of aluminum matrix composite is investigated. Feed rate, cutting speed, and depth of cut are input parameters. Tool life, tool wear, and cutting force are performance metrics. The LAM strengthens wear resistance, extends tool life, and decreases tool wear. The cutting forces are also decreased by LAM to a range of 32% to 52%. The LAM is used for the advancement of metal removal and tool life with less surface damage. By adjusting the material removal temperature, performance indicators, i.e., surface finish, tool wear, and cutting pressures, are evaluated. When compared with traditional machining, LAM minimizes tool wear and fiber pullout. The ideal metal removal temperature was determined to be 300°C at a feed rate of $0.03\ \text{mm/rev}$, depth of cut of $0.6\ \text{mm}$, and speed of $30\ \text{m/min}$. In comparison to traditional machining under the same cutting conditions, LAM offers a 65% decrease in surface finish and tool wear. Additionally, LAM demonstrates an improvement in the machining of the long fiber by higher material removal rate, decreased damage, and longer tool life. The ideal metal removal temperature with carbide tooling was determined to be 300°C at $0.3\ \text{mm/rev}$ feed, $0.75\ \text{mm}$ of cut depth, and $155\ \text{m/min}$ speed. When employing LAM instead of traditional machining under the same machining conditions, the specific cutting energy and surface finish

are lowered by 13% and 26% correspondingly. When the surface finish is 2 μm , the efficient tool span is enhanced 1.8–2.36 times compared with traditional machining based on cutting speed. LAM reduces surface finish and tool wear at all cutting speeds (55–205 m/min) compared with traditional machining.

1.4 Machining Requirements

Industries typically experience poor surface quality, high capital costs, and less tool life while cutting innovative engineered materials. Due to these materials' poor thermal conductivity, it is challenging to disperse the heat produced at the machining zone. By lowering the cutting temperature, the application of cutting fluids increased machinability; nevertheless, inappropriate treatment of these cutting fluids might have an adverse environmental impact. As the chips slide on the rake face of the tool and eliminate the job material during machining, the cutting tool is exposed to different stresses [44].

1.5 Tools to be Used

When cutting materials that are challenging to cut, cutting tools utilized in laser-aided machining should be able to withstand significant mechanical and thermal loads. Laser-assisted machining uses a variety of cutting tools, including coated carbide inserts, cubic boron nitride, and ceramics. Tools lose their hardness at temperatures exceeding the softening threshold. High-speed steel has a softening point of 605°C, carbide 1,110°C, Al_2O_3 1,400°C, and diamond and cubic boron nitride tool material 1,505°C [45, 46]. When cutting silicon nitride and zirconia, LAM employs PCBN inserts instead of carbide inserts [47]. For better surface roughness, titanium alloys are machined using carbide inserts. For the machining of superalloys, ceramic inserts are used to increase tool life, but these are not suitable for titanium alloys due to their poor hardness, lack of chemical affinity, and poor thermal conductivity. Carbide inserts are utilized with LAM of composites to get superior outcomes in terms of enhanced surface quality and greater tool life at higher cutting rates. Hardened AISI D2 steel is machined using carbide cutting tools. Since tool wear is a significant determinant of the workpiece's surface roughness, extending tool life would decrease tool wear and generally enhance the workpiece's surface quality.

1.6 Lasers for Machining

A coherent, converging, and monochromatic electromagnetic radiation beam is the hallmark of laser. It is made up of three main parts, i.e., a resonator, an optical delivery, and a path to stimulate the lasing medium into an amplifying condition. The laser state may be solid (such as Nd:YAG), liquid (dye), or gas (e.g., He, CO₂, etc.).

Nd:YAG, excimer, and carbon dioxide lasers are categorized into three main types, which are utilized for the machining of advanced materials. Gas lasers known as CO₂ lasers use the lasing medium of gas molecules, such as helium and carbon dioxide. The excitement of CO₂ is accomplished by raising the molecule's vibrational energy [48]. With a wavelength of 10 μm in the infrared range, CO₂ laser offers good beam quality and greater efficiency [49]. Nd:YAG is a solid-state laser that produces laser light by dispersing dopants like neodymium in a crystalline matrix of yttrium–aluminum–garnet. Krypton or xenon flash lamps are used to excite these sorts of lasers [50]. These lasers' shorter wavelengths (1 μm) may penetrate highly reflecting materials, which CO₂ lasers find challenging to work with [51].

Gas lasers include excimer lasers. Excited dimer, a combination of two similar kinds that only exists in a stimulated state, is where the word “excimer” first appeared. The output wavelengths of excimer complexes range from 0.194 to 0.352 μm in the ultraviolet to near-ultraviolet spectrum. The length of the laser emission, either pulsed or continuous wave laser, also serves to distinguish lasers. While CW lasers operate with a constant average beam power, pulsed mode lasers typically have pulse duration. Because the process parameters are more precisely controlled, pulsed lasers are desirable to continuous wave lasers for machining ceramics [52]. A framework is developed to study the micromilling abilities on thick poly-methyl-methacrylate utilizing several input responses and a soft computing technique, i.e., the Gaussian process regression is applied to prepare width, surface roughness, and depth prediction models using a CO₂ laser machine [53]. A unique approach is applied for the physical mechanism of gold film using laser machining of diamond microgroove [54].

1.7 Machining Requirements

A CNC lathe and dynamometer are used in the setup to measure the cutting forces applied to the tool. Using a charge amplifier, these cutting forces

are augmented. During machining, a pyrometer is utilized to gauge the workpiece's temperature operation. For machining, a laser generator produces the necessary laser power, which is then discharged by a laser gun onto the workpiece. A computer controller oversees all of these. In contrast to traditional turning and milling, laser-assisted machining utilizes laser energy to locally heat the workpiece. The method of removing material differs from traditional machining.

1.8 Conclusion

According to the review, it is evident that adding heat to the LAM method causes the surface layer of advanced materials to become softer, causing ductile distortion rather than brittle deformation to happen during machining. Due to the decrease in flow stress, cutting forces, and rubbing between the chip and tool, this makes machining simple. LAM has been proven to enhance surface quality and other surface properties.

References

1. Germain, G., Dal Santo, P., Lebrun, J.L., Comprehension of chip formation in laser assisted machining. *Int. J. Mach. Tools Manuf.*, 51, 230, 2011.
2. Majumdar, J.D. and Manna, I., *Laser assisted fabrication of materials*, Springer Series in Materials Science, vol. 161, Springer Verlag Berlin Heidelberg, Germany, 2013, ISBN 978-3-642-28358-1.
3. Sun, S., Brandt, M., Mo, J., Current progresses of laser assisted machining of aerospace materials for enhancing tool life. *Adv. Mater. Res.*, 690–693, 3359, 2013.
4. Jeon, Y., Wook Park, H., Lee, C.M., Current research trends in external energy assisted machining. *Int. J. Precis. Eng. Manuf.*, 14, 337, 2013.
5. Dong-hyeon, K. and Choon-man, L., Development of a one-axis manipulator for laser assisted machining. *J. Cent. South Univ.*, 20, 378, 2013.
6. Armitage, K., Masood, S., Brandt, M., An investigation on laser assisted machining of hard to wear materials. *Proceedings of the 2nd Pacific International Conference on Applications of Lasers and Optics*, PICALO, Melbourne, Australia, 2006.
7. Chang, C.W. and Kuo, C.P., Evaluation of surface roughness in laser-assisted machining of aluminum oxide ceramics with Taguchi method. *Int. J. Mach. Tools Manuf.*, 47, 141, 2007.

8. Kuar, A.S., Doloi, B., Bhattacharyya, B., Modelling and analysis of pulsed Nd:YAG laser machining characteristics during micro-drilling of zirconia (ZrO₂). *Int. J. Mach. Tools Manuf.*, 46, 1301, 2006.
9. Kalpakijan, S. and Schmid, S., *Manufacturing engineering and technology*, Fourth edition, Pearson Hall Press, India, 2002.
10. Chryssolouris, G., Anifantis, N., Karagiannis, S., Laser assisted machining: An overview. *Trans. ASME*, 119, 766, 1997.
11. Nabhani, F., Machining of aerospace alloys. *Rob. Comput.-Integr. Manuf.*, 17, 99, 2001.
12. Arunchalam, R. and Mannan, M.A., Machinability of nickel-based high temperature alloys. *Mach. Sci. Technol.*, 4, 1, 127, 2000.
13. Ezugwu, E.O., Key improvements in the machining of difficult-to-cut aerospace super alloys. *Int. J. Mach. Tools Manuf.*, 45, 1353, 2005.
14. Wang, Z.Y., Rajurkar, K.P., Fan, J., Lei, S., Shin, Y.C., Petrescu, G., Hybrid machining of Inconel 718. *Int. J. Mach. Tools Manuf.*, 43, 1391, 2003.
15. Shokrani, A., Dhokia, V., Newman, S.T., Environmentally conscious machining of difficult-to-machine materials with regard to cutting fluids. *Int. J. Mach. Tools Manuf.*, 57, 83, 2012.
16. Melkote, S., Kumar, M., Hashimoto, F., Lahoti, G., Laser assisted micro-milling of hard to-machine materials. *CIRP Ann.-Manuf. Technol.*, 58, 45, 2009.
17. Rozzi, J.C., Pfefferkorn, F.E., Incropera, F.P., Shin, Y.C., Transient, three-dimensional heat transfer model for the laser assisted machining of silicon nitride Comparison of predictions with measured surface temperature histories. *Int. J. Heat Mass Transf.*, 43, 1409, 2000.
18. Rozzi, J.C., Pfefferkorn, F.E., Shin, Y.C., Experimental evaluation of the laser assisted machining of silicon nitride ceramics. *Trans. ASME*, 122, 666, 2000.
19. Mun, S.D., Micro machining of high-hardness materials using magnetic abrasive grains. *Int. J. Precis. Eng. Manuf.*, 11, 763, 2010.
20. Dandekar, C.R., Shin, Y.C., Barnes, J., Machinability improvement of titanium alloy (Ti-6Al-4V) via LAM and hybrid machining. *Int. J. Adv. Manuf. Technol.*, 50, 174, 2010.
21. Anderson, M., Patwa, R., Shin, Y.C., Laser Assisted machining of Inconel 718 with an economic analysis. *Int. J. Adv. Manuf. Technol.*, 48, 1879, 2006.
22. Skvarenina, S. and Shin, Y.C., Laser-assisted machining of compacted graphite iron. *Int. J. Adv. Manuf. Technol.*, 46, 7, 2006.
23. Rebro, P.A., Shin, Y.C., Incropera, F.P., Laser-assisted machining of reaction sintered Mullite ceramic. *J. Manuf. Sci. Eng. Trans. ASME*, 124, 875, 2002.
24. Lei, S., Shin, Y.C., Incropera, F.K.P., Deformation mechanisms and constitutive modeling for silicon nitride undergoing laser assisted machining. *Int. J. Adv. Manuf. Technol.*, 40, 2213, 2000.

25. Lei, S., Shin, Y.C., Incropera, F.P., Experimental investigation of thermo-mechanical characteristics in laser-assisted machining of silicon nitride ceramics. *J. Manuf. Sci. Eng., Trans. ASME*, 123, 639, 2001.
26. Kim, J.D., Lee, S.J., Jeong, S., Characteristics of laser assisted machining for silicon nitride ceramic according to machining parameters. *J. Manuf. Sci. Eng.*, 25, 995, 2011.
27. Ding, H. and Shin, Y.C., Improvement of machinability of Waspaloy via laser assisted machining. *Int. J. Adv. Manuf. Technol.*, 64, 475, 2013.
28. Dandekar, C.R. and Shin, Y.C., Experimental evaluation of laser-assisted machining of silicon carbide particle-reinforced aluminum matrix composites. *Int. J. Adv. Manuf. Technol.*, 66, 1603, 2013.
29. Rashid, R.A.R., Sun, S., Wang, G., Dargusch, M.S., Experimental investigation of laser assisted machining of AZ91 magnesium alloy. *Int. J. Precis. Eng. Manuf.*, 14, 1263, 2013.
30. Anderson, M.C. and Shin, Y.C., Laser-assisted machining of an austenitic stainless steel: P550. *Proc. Inst. Mech. Eng., Part B: J. Eng. Manuf.*, 220, 2055, 2006.
31. Dumitrescu, P., Koshy, P., Stenekes, J., Elbestawi, M.A., High-power diode laser assisted hard turning of AISI D2 steel. *Int. J. Adv. Manuf. Technol.*, 46, 2009, 2006.
32. Sun, S., Brandt, M., Dargusch, M.S., Characteristics of cutting forces and chip formation in machining of titanium alloys. *Int. J. Adv. Manuf. Technol.*, 49, 561, 2009.
33. Bermingham, M.J.J., Sun, S.K., Palanisamy, S., Dargusch, M.S., New observations on tool life, cutting forces and chip morphology. *Int. J. Adv. Manuf. Technol.*, 51, 500, 2011.
34. Bermingham, M.J., Sun, S., Palanisamy, S., Dargusch, M.S., Understanding the tool wear mechanism during thermally assisted machining Ti-6Al- 4V. *Int. J. Adv. Manuf. Technol.*, 62, 76, 2012.
35. Rahman Rashid, R.A., Sun, S., Wang, G., Dargusch, M.S., An investigation of cutting forces and cutting temperatures during laser assisted machining of the Ti-6Cr-5Mo-5V-4Al beta titanium alloy. *Int. J. Adv. Manuf. Technol.*, 63, 58, 2012.
36. Germain, G., Lebrun, J.L., Braham-Bouchnak, T., Bellett, D., Auger, S., Laser Assisted machining of Inconel 718 with carbide and ceramic inserts. *Int. J. Mater. Form.*, 1, 523, 2008.
37. Attia, H., Tavakoli, S., Vargas, R., Thomson, V., Laser-assisted high-speed finish turning of super alloy Inconel 718 under dry conditions. *CIRP Ann. – Manuf. Technol.*, 59, 83, 2010.
38. Rebro, P.A., Shin, Y.C., Incropera, F.P., Laser-assisted machining of reaction sintered Mullite ceramic. *J. Manuf. Sci. Eng. Trans. ASME*, 124, 875, 2002.
39. Pfefferkorn, F.E., Shin, Y.C., Tian, Y., Incroper, F.P., Laser-assisted machining of magnesia-partially-stabilize zirconia. *J. Manuf. Sci. Eng. Trans. ASME*, 126, 42, 2004.

40. Ding, H. and Shine, Y.C., Laser-assisted machining of hardened steel parts with surface integrity analysis. *Int. J. Adv. Manuf. Technol.*, 50, 106, 2010.
41. Masood, S.H., Armitage, K., Brandt, M., An experimental study of laser-assisted machining of hard-to-wear white cast iron. *Int. J. Adv. Manuf. Technol.*, 51, 450, 2011.
42. Dandekar, C.R. and Shin, Y.C., Laser-assisted machining of a fiber reinforced metal matrix composite. *J. Manuf. Sci. Eng. Trans. ASME*, 132, 06100, 2010.
43. Wang, Y., Yang, L.T., Wang, N.J., An investigation of laser assisted machining of Al₂O₃ particle reinforced metal matrix composites. *J. Manuf. Sci. Eng.*, 129, 268, 2002.
44. Aggarwala, A., Singh, H., Kumar, P., Singh, M., Optimization of multiple quality characteristics for CNC turning under cryogenic cutting environment using desirability function. *J. Mater. Process. Technol.*, 205, 42, 2008.
45. Ezugwu, E.O., Bonney, J., Yamane, Y., An overview of machinability of aero engine alloys. *J. Mater. Process. Technol.*, 134, 233, 2003.
46. Rebro, P.A., Shin, Y.C., Incropera, F.P., Design of operating conditions for crack free laser-assisted machining of mullite. *Int. J. Adv. Manuf. Technol.*, 44, 677, 2004.
47. Majumdar, J.D. and Manna, I., Laser processing of materials. *Sadhana*, 28, 495, 2003.
48. Dubey, A.K. and Yadava, V., Laser beam machining—A review. *Int. J. Mach. Tools Manuf.*, 48, 609, 2008.
49. Tabata, N., Yagi, S., Hishii, M., Present and future of lasers for fine cutting of metal plate. *J. Mater. Process. Technol.*, 62, 309, 1996.
50. Samant, A.N. and Dahotre, N.B., Laser machining of structural ceramics—A review. *J. Eur. Ceram. Soc.*, 29, 969, 2009.
51. Meijer, J., Laser beam machining (LBM), state of the art and new opportunities. *J. Mater. Process. Technol.*, 149, 2, 2004.
52. Islama, M.U. and Campbella, G., Laser machining of ceramics: A review. *Mater. Manuf. Processes*, 8, 611, 1993.
53. Anjum, A., Shaikh, A.A., Tiwari, N., Experimental investigations and modeling for multi-pass laser micro-milling by soft computing-physics informed machine learning on PMMA sheet using CO₂ laser. *Opt. Laser Technol.*, 158, 108922, 2023.
54. Wei, X., Wen, Q., Chen, J., Lu, J., Cui, C., Huang, G., Jiang, F., Research on gold film-assisted ultraviolet nanosecond laser machining of diamond microgrooves. *Opt. Laser Technol.*, 158, 108793, 2023.

