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Review IJMMP

Review on Recent Trends in Laser Assisted Machining of Hard to Cut Materials

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Abstract

Laser-assisted machining (LAM), an alternative method of fabricating hard-to-machine materials, like ceramics, composites, Titanium alloy, Nickel based alloy are being developed and widely utilized in aerospace, automotive, medical and nuclear industries due to their special properties. These materials posing many challenges when machined with the help of Conventional methods of machining. Conventional methods of machining these materials are found to be uneconomical. Among the various external energy assisted machining methods, laser assisted machining (LAM) has received the more attention within the metal cutting domain and few of research was carried during the recent years. Laser assisted machining uses a focused laser beam to heat local areas of the workpiece and remove softened material from the ductile region, leaving high quality and crack-free surfaces. The study of LAM for hard to machine materials has been attracting progressively more interest from researchers in academia and industry. The study of machining mechanisms for different hard-to-machine materials therefore becomes very important in LAM. Currently LAM has been successfully applied in major mechanical machining processes such as turning, milling, grinding, and some non-traditional mechanical machining processes such as electrochemical machining and water jet machining. This paper is aimed to review and summarize the possible use of LAM for hard to machine materials. The review also presents a perspective on future development trends for laser assisted machining technology.

Keywords: Laser Assisted Machining, Ti Alloy, Ni Alloy, Ceramics, Composites.

INTRODUCTION

The material is termed as hard-to-machine if it possesses any of the subsequent properties, like higher toughness, increased resistance to corrosion and fatigue, low thermal conductivity, high hardness and brittleness, and high strength to weight ratio. On extreme machining conditions these characteristics cause increased tool wear, higher heat generation, increased cutting energy, poor surface finish, and difficulty in chip formation [1]. This might have a big effect of machining process performances like poor machinability, high machining cost and low productivity. Due to the inherent characteristics of hard-to-machine materials, conventional machining methods like milling or turning are proving inefficient [2]. The laser beams are extensively utilized for welding, sintering, cutting, drilling, heat treatment and marking [2, 3]. Laser beam machining (LBM) is taken into account suitable for hard-to-machine materials, due to its independent nature on materials hardness and trading vitality [4]. Laser is getting more popularity due to its beam intensity at low mean power, good focusing characteristics during very small pulse duration, small kerf widths

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and narrow heat effected zones, high productivity, reduced process, eco-friendliness, low manufacturing cost and better surface finish [5].

Laser Assisted Machining-Outline

As compare to conventional machining, LAM process saves more energy by reducing the cutting force and making the method as a green machining one. The laser heat source is applied before the cutter enhancing the material removal temperature. This makes the fabric softer and machining process a neater one by reducing the flow stress and strain hardening of the fabric without compromising the micro-structural changes and properties of the material [6]. Figure 1 shows a schematic of laser assisted machining.

In LAM experiments two main laser sources are widely used CO_2 laser & Nd:YAG laser. Nd:YAG laser having a shorter wavelength, has better absorpivity.CO_2 laser has less suitable on most of the difficult to cut material such as inconel, hardened steel and composite materials when compared to Nd:YAG due to low absorptivity of laser energy [8-10].

Material Removal Mechanism in LAM

In LAM process, the heat energy is applied at the shear zone of the work material leading to increased heat generation at that time. The generated heat is carry out by the chip partially. Hence, the choice of laser heat source should be done properly [11]. The assistance of laser during machining results in benefits like reduced cutting forces, minimal tool wear, lesser power consumption [12]. LAM process is highly recommended for the hard to cut materials like engineering ceramics, titanium and nickel alloys, substantial strain hardening material like austenitic stainless steels, etc. [13]. Depending on application of the component, the type of LAM process is selected. Some of the conventional LAM processes are laser-assisted turning, laser-assisted milling, laser-assisted grinding, and laser-assisted turn-mill. Laser-assisted turning process is commercially used and studied by many researchers, especially for machining hard to cut materials ceramics like silicon nitride, alumina, and obtained encouraging results [14].Milling in LAM process is yet to commercialize due to the difficulty in controlling the heat source and tool path during machining. Hence, research and development on LAM are still expanding [15, 16]. The schematic representation of LAM turning, LAM milling, and LAM grinding is shown in Figure 2.

Laser-Assisted Machining pf Hard-to-Machine Materials

LAM has identified an important area of research and has been demonstrated to be able to improve the machinability of a variety of hard-to-machine materials in terms of a reduction of cutting force, better surface finish, and longer tool life [17]. This section will introduce the effect laser parameters together with machining parameters on different hard–to-machine materials are reviewed in this paper.

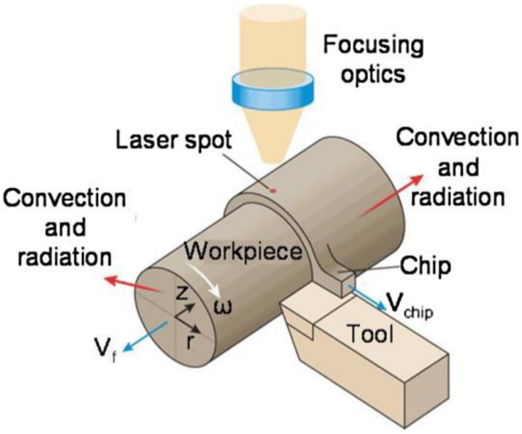

Figure 1. Laser-assisted machining [7].

Titanium Alloys

Titanium and its alloys are interesting materials which have been in high demand in aerospace, automotive, and biomedical industries predominantly due to their superior properties such as high strength-to-weight ratio, strong wear and corrosion resistances, high creep, and ability to retain high strength at high temperature [18, 19]. This demand has resulted in the requirement to increase machining speed and consequently the material removal rate. Table 1 shows summery of latest researches in LAM of Titanium alloys

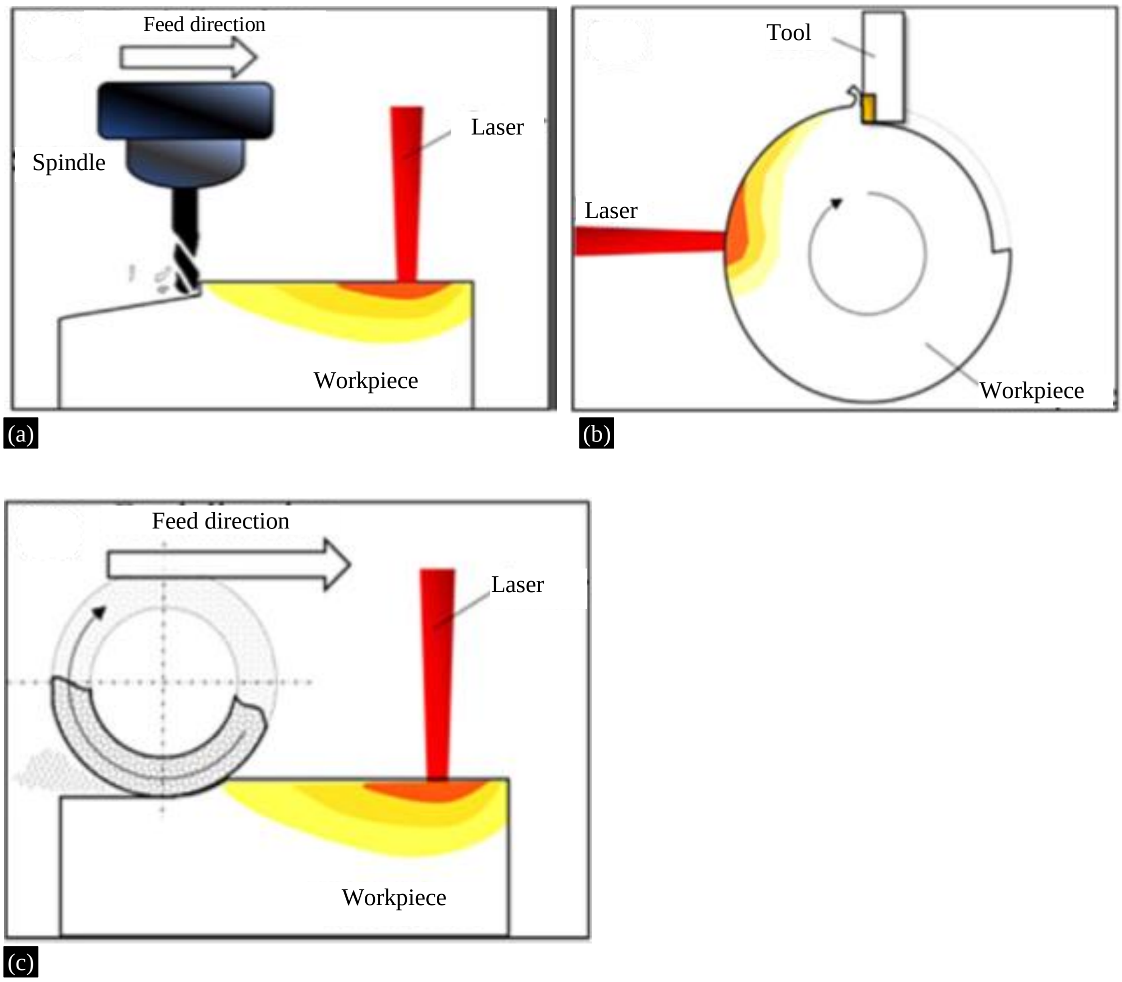

Figure 2. Schematic of (A) LAM turning, (B) LAM milling, and (C) LAM grinding [16].

Table 1. Summery of latest researches in LAM of Titanium alloys

Reference	Input variables	Performance Measures	Findings
Ajit Joshi et al. (2014) [20]	spot radius, laser power and scanning speed	Temperature Distribution across Depth of workpiece	The results show that, the FEM model was developed to study and predict temperature distribution in the workpiece and to establish the optimum depth of cut for laser assisted machining.
S.A. Kochergin et al. (2017) [21]	Cutting speed, Gas pressure focal Length	Cutting width, Minimum dross Surface roughness	To minimize an amount of dross frequency radiation mode at about 100–200 Hz with the maximum speed of the cut. Experimental result shows that As cutting speed increases Cutting width decreased by 30% surface roughness also decreases
R. Farasati et al. (2019) [22]	laser power, pulse	MRR, Taper	It was found from the results that time interval and laser power have great influence on MRR and

Reference	Input variables	Performance Measures	Findings
	frequency gas pressure, pulse interval & width		taper, respectively.
H. Abdollahi et al. (2019) [23]	Ultrasonic vibration amplitude, laser power, pulse frequency and gas pressure	MRR Recast layer thickness, Taper	Results indicated that the vibration amplitude has greatest effect on improving the MRR and RLT. selection of 40 mm vibration amplitude, 980 W laser power,1200 Hz modulation frequency and 0.25 MPa gas pressure is an optimal parameter setting yields material removal rate of2 mm3 /min and RLT of 439 mm. The desirability for this parameter setting is 78%.
T. Muthuramalingam et al. (2020) [24]	Nozzle distance power, focal length gas pressure	Roundness Ovality	Results indicated that power has the most significant impact on determining the dimensional accuracy. 1.2 mm (ND), 2 mm (L), 4bar (GP) and 2kW (J) has been chosen as optimal process parameters. Power and gas pressure are highly significant on determining machining accuracy in LBM drilling process. Power and nozzle distance are highly significant on determining accurate roundness in LBM.
H. Kim, et al. (2020) [25]	Heat affected zone Feed rate	Cutting force surface roughness	In this study, the machining characteristics of Inconel 718 and Ti6Al-4 V were investigated using LAM, IAM and CM. However, the LAM can be considered a more efficient than TAM method because the induction heat source is more likely to be affected by feed rates than the laser heat source. For IAM is recommended to have low feed rate.

Nickel-Based Super Alloys

Nickel alloys have been continuously developed and research is being carried out to enhance the mechanical properties especially the good strength and high temperature resistance. High corrosion resistance and sustainability at elevated temperatures make these alloys useful especially in aggressive environments. Inconel 718 is one of the materials employed in such environments. It is Ni-Cr-Fe-based alloy characterized by high strength, fatigue, and creep properties. The period of work hardening and heat softening will form segmented chip and cause severe tool wear. Adhesive and abrasive wear are dominant wear mechanisms, which lead to flank wear and notching wear as the main tool failure modes in conventional machining of Inconel 718. Due to the thermal softening in LAM, the cutting forces are lower than those in conventional machining. Ceramic tool inserts are found to have better performance than carbide tools in terms of attainable surface roughness and residual stress in LAM of nickel-based alloys [26]. Table 2 shows summery of latest researches in LAM of Nickel based super alloys.

Table 2. Summery of latest researches in LAM of Nickel based super alloys.

Reference	Input variables	Performance Measures	Findings
K. Venkatesan et al. (2014) [27]	Cutting speed, Feed rate, Laser power	cutting forces, Temperature, hardness	The analysis of results reveals that cutting speed & laser power has maximum influence on the cutting force components compared to feed rate. There is no change in the hardness value (48HRC) of the machined surface due to laser heating. The cutting forced compare with conventional machining, a maximum 60% reduction of cutting force was observed for LAM at optimal combinations
Giacomo Leopardi et al. (2015) [28]	Laser Power Cutting Speed Feed per Tooth Defocus	cutting forces, Tool wear, Tool Deflection	LAM, using the ceramic tool under the given conditions, Significant drop in machining forces, tool deflection and also tool wear could be reduced by laser heating. Laser assisted milling reduces Fa and VBmax at vc = 800 m/min and fz =

Reference	Input variables	Performance Measures	Findings
	Milling Mode		0.16 mm compared to conventional milling.
Z.Pan et al. (2017) [29]	laser power and scanning speed spot Diameter	Laser-assisted milling Temperature Heat-affected zone Modeling	The effects of laser scanning speed and power input on the melting zone shape are investigated. The maximum melting zone area is achieved when the power input of 1000 W and scanning speed at 1000 mm/min.
S C. Borse et al. (2018) [30]	scanning speed, frequency, Power	MRR, surface finish	In Fiber laser micro milling operation on Inconel 718.Result shows that power is most significant factor among frequency and speed. The Minimum Experimental value of Surface Roughness is 0.372 µm that is obtained with Power 30%, pulse frequency 38 kHz and Scanning Speed 990 mm/s.
A.K.M et al. (2019) [31]	Laser power Travel speed Gas pressure Nozzle Diameter	MRR. Surface roughness Kerf wall inclination	The experimental investigation on CO2 laser machining of Inconel 718 superalloy are reported in this study. Laser power and travel speed significantly influenced kerf wall inclination and material removal rate.
D. Xu et al. (2020) [32]	Laser power Laser scanning speed Cutting speed Cutting depth Cutting width Feed rate	Surface integrity Residual stress Chip formation Fatigue life	The present research gives a comprehensive investigation on the surface integrity of laser-assisted milling (LAMill) process with an in-depth study of the mechanism of chip formation, Fatige life.

Ceramics

Advanced engineering materials, such as Al_2O_3, Si_3N_4, and ZrO_2, are good wear resistance. However, they are difficult to machine using conventional machining techniques due to their high hardness and brittleness. LAM has been found to be able to improve ceramics machinability through preheating [33]. Heating using a laser to modify the deformation behavior of ceramic can change its property from brittle to ductile. It can also reduce the yield strength of the ceramic to a value below the fracture strength, thereby eliminating melting or sublimation of the work piece surface or destruction of the subsurface [34, 35] (Table 3).

Table 3. Provide summery of latest researches in LAM of Ceramics.

Reference	Input variables	Performance Measures	Findings
Venkatesh Kannan et al. (2014) [36]	Laser power, spot size, laser-tool lead, cutting speed, feed Surface Temperature	Cutting force Specific Cutting Energy Tool wear	The results show that, the surface temperature plays major role on cutting forces, and tool wear in LAM. It was observed that the increase in surface temperature above 850°C resulted in reduction of cutting forces and tool wear
Hossein Roostaei et al. (2016) [37]	Spot Diameter Laser Power Feed Rate	FEM Temperature distributions Three-dimensional heat transfer	Experimental & Analytical results show that, the thermometer measurements are slightly lower than the simulation results in the range of 25 to 43s.Differences between numerical predictions and experimental measurements for the time interval 25 s and 43 s increase significantly. The maximum temperature difference is about 40k in the range of 0 to 50 s.
G. Guerrini et al./(2018) [38]	laser power, scanning speed,	Cracking hybrid machining; grinding.	Two laser strategies were developed. Both of them led to a decrease in grinding force of about 30%.
Y. Yang,	Speed, feed	cutting	The minimum cutting and thrust forces were achieved when the

Reference	Input variables	Performance Measures	Findings
et al. (2019) [39]	rate, Depth of cut laser power, scanning speed, Micro milling	forces, surface roughness Tool wear,	cutting speed, feed per tooth and depth of cut were 31.4m/min, 0.3 μm/z and 2μm, respectively. The surface roughness recorded was Ra of 46nm.When compare with conventional milling using the same parameters. The surface quality fabricated by LOMM was better than that by the conventional micro milling. The machining efficiency in LOMM was improved by 104% as compared to the conventional micro milling.
Y. Pu, et al. (2019) [40]	Laser Assisted machining, Laser power, MRR 3 D surface Topography	Chip Tool wear Surface Microstructur e	In this study, the three-dimensional (3D) topography of a machined Si3N4 surface using laser assisted machining (LAM) under different material removal modes was comprehensively characterized and compared using the standard ISO 25178–2:2012surface texture parameters. LAM is effective for machining ceramics with a high hardness and high brittleness. Different material removal modes were obtained by changing the power of the laser and were inferred by comprehensively analyzing the macroscopic and microscopic topography of the chips, tool wear and machined surface.
Z. Ma, et al. (2020) [41]	feed, laser spot size, depth-of-cut, laser power,	Surface quality Surface morphology Subsurface damage	The results show that LAG can easily achieve ductile regime grinding in the same machine tool. The maximum improvement in surface roughness Rz and Ra reached 40.8% and 29.7%, respectively.

Composites

Composites are usually inhomogeneous and anisotropic in nature as a combination of reinforcement (usually a ceramic, such as Al_2O_3, SiC, etc.) fibers or whiskers with matrix metal (normally ductile metals, such as aluminum alloy). The reinforcement enhances hardness and wear resistance. However, it causes excessive tool wear. LAM is found to be able to consistently improve machinability of composites. The laser preheating will soften the reinforcement and lead to a reduction in cutting force compared to conventional machining. The machined surface roughness is controlled by particle fracture and pullout. The wear resistance of the workpiece is therefore increased. Higher compressive residual stress which is three times higher than conventional machining is reported by using LAM [2] (Table 4).

Table 4. Provide summery of latest researches in LAM of Composites

Reference	Input variables	Performance Measures	Findings
Damian Przestacki et al (2014) [42]	cutting speed laser power feed rate depth of cut	Tool wear	In this study, laser-assisted machining on A359/20SiCp material was compared with conventional turning process. It was found, by using lam machinability improved, lower tool wear, and thus increased tool life, as well as reduction of cutting time.
A. Mahamani, et al. (2017) [43]	speed, laser power, standoff distance	Entry diameter, exit diameter, and taper	The contribution of this study is to analyze the influence of reinforcement ratio of the composites and machining parameters on the responses.
M. Putz et al. (2018) [44]	Feedrate composite thickness Jet diameter Working distance	High precision machinability 2D-and 3D-layer composites	This study verifies the high precision machinability of 2D- and 3D-layer composites out of CFRP and a lightweight metal such as aluminum or magnesium using the abrasive Water jet. The 3 Dstrategy allows for composites with a steady surface quality and higher forces that can be transmitted between the two material partner. Besides economical cutting strategy.
S. Marimuthu,	Laser power Cutting speed	Surface roughness	This study contains details oflaser cutting of 2mm thick aluminium metal matrix reinforced with aluminium oxide

Reference	Input variables	Performance Measures	Findings
et al. (2019) [45]	Gas pressure Gas composition	Kerf width Heat affected zone	fibre (Al MMC). The experimental results show that the laser cutting mechanisms of fibre reinforced MMCs are vastly different from the mechanisms observed in laser cutting of monolithic metals and alloys.
C. Wei, et al. (2020) [46]	Laser power Laser power density Laser beam diameter Cutting speed	Cutting force Surface quality Tool wear MRR Productivity	This study report a new approach of high speed and high-power density laser-assisted turning (LAT) of an Al-SiC MMC. In which a smaller laser beam spot (0.7 mm), higher cutting speed (188−565 m/min), and higher laser power density (1.95–3.38 × 106 W/cm^2) were used. The optimum laser pre-heat temperature (324°C), minimum flank wear (166 μm), the lowest cutting force, and the best surface finish (0.72 μm, Ra), highest MRR (42375.00 mm^3/min), was achieved. The surface quality has been improved in addition to reduced tool wear.

Tool Materials for Machining Hard to cut Materials

A major requirement of cutting tool materials used for machining hard to cut materials is that they must possess adequate hot hardness to withstand elevated temperatures generated at high speed conditions. The different types of cutting tools, ceramics, coated carbide inserts, CBN, PCD, PCBN are employed in LAM.

Scope for Research in LAM Process

Advantages of LAM over conventional machining attracted many researches on the improvement of machinability benefits difficult-to-cut material. Few studies have been systematically investigated to select the optimum value of LAM parameter for obtaining minimum cutting force, reasonably good MRR and effect of type of cutting tool materials on the wear mechanism. It is difficult to find the optimal machining parameters due to the complexity of influence parameters and their interaction effects. This review focused to characterize the laser assisted machining process by identifying how individual parameter affects the machining results.

CONCLUSION

The current study presents a review of different approaches used for experimental and analytical investigations on laser assisted machining (LAM) of various hard to cut materials. The physical mechanism during the LAM process is also described. The qualitative difference between LAM and conventional machining process is demonstrated. The main input parameters which affect the quality characteristics are laser parameters (laser power, scan speed, wavelength etc.), mode of operation, machining parameters, material parameters (type, thickness, etc.), etc. The important output responses studied in various papers are machined geometry, surface roughness and metallurgical characteristics.

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