LASER BEAM MACHINING OF INCONEL ALLOYS: A REVIEW

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Abstract

Inconel alloys are one of the commonly used alloys in manufacturing field due to their excellent strength-to-weight ratio, high corrosion resistance and strength at relatively high temperature. This review briefly evaluates the work carried out on the significance of various laser beam machining processes on Inconel alloys and also a brief study has been done on the effects of various element composition on the Inconel properties. An overview of research works on Inconel alloys using laser beam machining is being given in this paper. Most of the research works have investigated properties like micro-hardness, tensile strength, thermal properties and mechanical properties. Some works are concentrated on finding the optimum cutting force and cutting temperature using various process parameters like cutting speed, feed rate and laser power. It has been concluded that simulation models and optimization techniques can be a part of future research works.

Key words: cutting force, cutting temperature, Inconel alloys, laser beam machining, properties, process parameters

I. INTRODUCTION

Inconel alloys are nickel based super alloys having excellent strength-to-weight ratio, high corrosion resistance and possess high strength at relatively high temperature. Inconel are preferred over titanium alloys used in aerospace and nuclear industries such as gas turbines, jet engines and thrust reservoir due to chemical and mechanical properties at elevated temperature [1]. These alloys are described as difficult to cut materials as many problems are encountered during machining them such as excessive heat generation in cutting zone and high friction between tool-chip interface, tendency for BUE formation and catastrophic failure of cutting edge [2, 3, 4]. Due to such properties of Inconel alloys, traditional machining processes like milling, turning are proving to be highly uneconomical. Laser beam machining (LBM) is offering as an effective alternative due to its cost effectiveness and high accuracy. Nickel alloys are widely being machined using various LBM processes like selective melting process, laser sintering process, laser assisted machining process etc. This paper highlights the machining of Inconel with the application of LBM process with the effect of various lasing process parameters. Further it summarizes the effects of various elemental compositions of the Inconel alloys.

II. EFFECTS OF VARIOUS LASER PROCESSES ON INCONEL ALLOYS:

A. Selective laser melting (SLM):

The mechanical qualities of Inconel alloys were found to improve after being heat treated post SLM process. Heat treatment of IN 718 resulted in higher micro-hardness (470Hv) than SLM sample (365Hv) [5] along with higher tensile strength (UTS) (1280–1358 MPa).

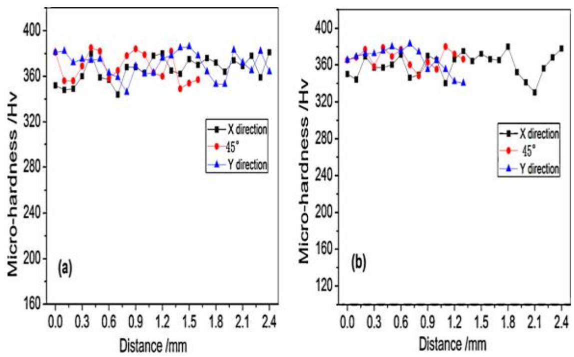

Fig 1:Micro hardness of SLMed IN718 samples on cross section (a) and vertical section (b). [5]

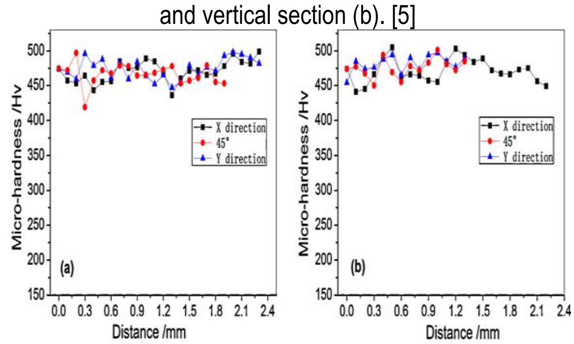

Fig 2:Microhardness of SLM + HTed IN718 samples on cross section (a) and vertical section (b). [5]

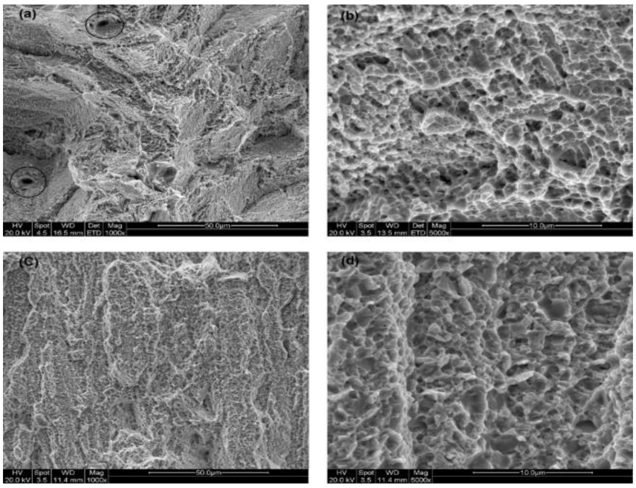

Fig 3:Fractographs of IN718 at different states and room temperature.(a)SLMed samples at a low magnification,(b)SLMed samples at a high magnification, (c) SLM + HTed samples at a low magnification and (d) SLM + HTed samples at a high magnification.[5]

Heat treatment followed by hot pressing process resulted in improve bonds between subsequent layers reducing anisotropy and increasing grain size of Inconel 718. [6].

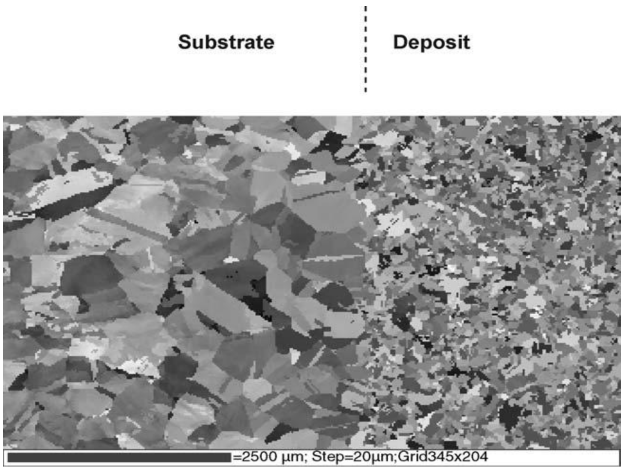

Fig 4:Interface zone following HIPing and heat treatment. This shows that considerable grain growth occurred within the substrate material.[6]

Li et al. [7] found that after heat treatment IN625 microstructure had fewer lattices constant due to precipitation of large number of NbC and MoC carbides from the matrix and a zigzag grain boundary was formed

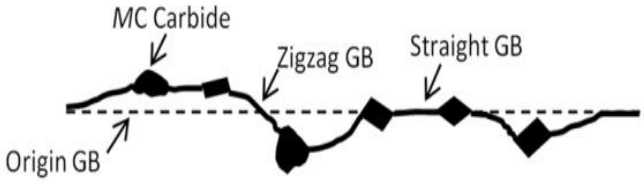

Fig 5:Zig zag boundary formation[7]

Kanagarajah [8] et al. found that in case of IN 939, heat treatment reduced the cyclic load and ductility and increased the yield strength to considerable amount compared to cast material. Recycling Inconel powders is economical in the manufacturing process. Mechanical composition and grain size of recycled IN 718 powder was found unchanged when used on parts machined by SLM [9].B.S. Yilbas investigated electrochemical response of laser surface melted Inconel 617 alloy and found that laser treated workpieces result in improved corrosion rates. Seawater corrosion behavior of laser surface modified Inconel 625 alloy was studied by Cooper et al. indicating that to minimize seawater corrosion of laser-modified surfaces, the microstructures had to be homogenized and, while adding particulate material, dissolution and alloying had to be avoided.

Laser sintering:

Research attempts has indicated that laser scan speed is to proportional to micro-hardness and is inversely proportional to density and dimensional accuracy in IN 625 when parameters like hatch spacing, laser power, beam diameter, scan speed and energy density were considered[12].

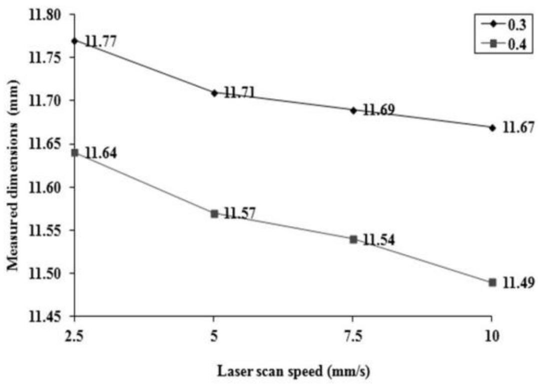

Fig 6: variation of dimensional accuracy with laser scan speed [12]

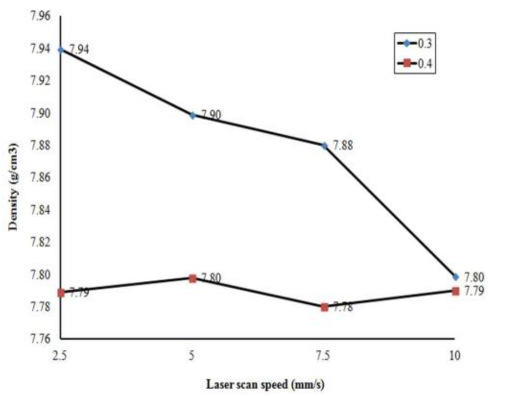

Fig 7: variation of density with laser scan speed [12]

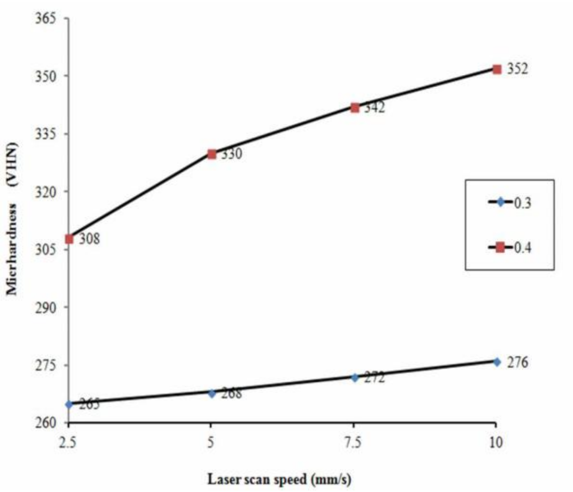

Fig 8: variation of microhardness with laser scan speed [12]

Further researches have been done to find the effect of various lasing parameters on Inconel while undergoing laser sintering manufacturing process. It has been found that higher laser power increases porosity and results in a strongly textured structure in direct laser fabrication of IN 718 [13].

Laser assisted machining (LAM):

Most of the current research works are being focused on laser assisted machining (LAM). It has been found that LAM results in improved hardness and tensile strength in Nano-TiC powder reinforced Inconel 625[14]. This is because of improved grain refinement by addition of Nano-TiC particles. .It has been found by researchers that LAM can be used to improve the machinability of Inconel by reducing the tool wear rate and machining forces. The integrity of machined surface (roughness, surface/sub-surface damage, residual stress, micro hardness), is improved slightly with the use of ceramics inserts in LAM over conventional machining [15].A comparative analysis of ceramic and carbide inserts using LAM is experimented and was found that life of uncoated carbide insert is less compared to traditional machining [16].

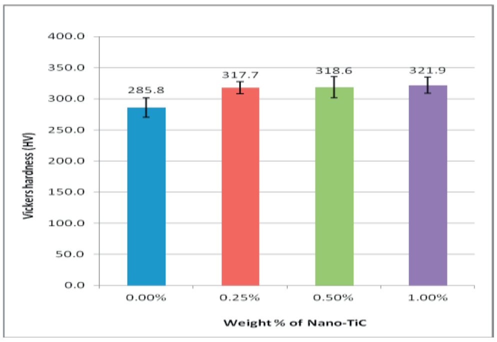

Fig.9: Comparison of micro-hardness [14]

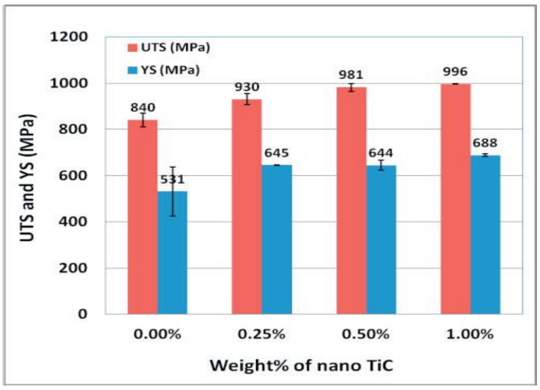

Fig.10: Comparison of tensile strength [14]

Further experiments carried with Sailon cutting tool and reported that surface roughness improved by 25% for ceramic tool which yielded better result with previous research associated with poor surface quality [17]. The Sailon ceramic tool demonstrated 800% increase in material removal rate and 50% improved tool life compared to conventional machining [16]. Shi et al. and Attia et al. reported that the tendency to form a segmented chip and strain in the primary shear zone are higher during LAM of Inconel 718 alloy compared with those in conventional machining because of a reduction in the strength of work piece as a result of thermal softening

Laser cutting:

The laser cutting process depends on the type of laser being used. Research works have indicated that femtosecond lasers cause minimal heat effected zone compared to nanosecond pulsed laser. While machining IN738 super alloy, it was found that an optimal laser focus can result in narrow kerf width [19].

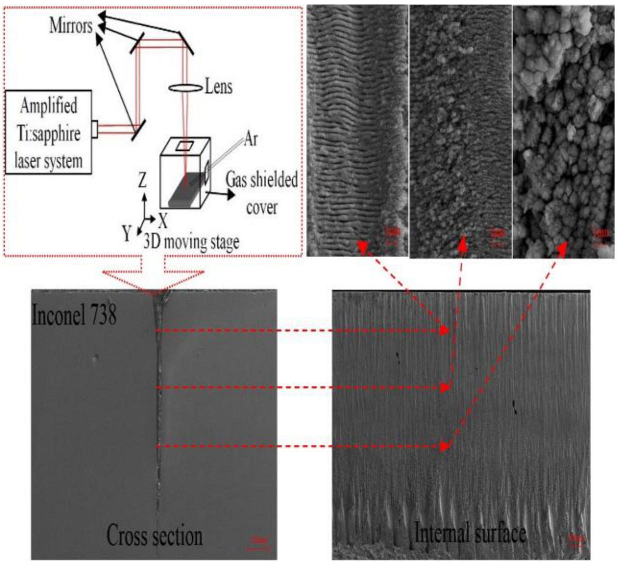

Fig 11: Microstructure morphology in the Inconel 738 kerf by femtosecond laser beam cutting [19]

It was found that surface roughness of Inconel 718 was mainly affected by cutting speed while using CW Nd: YAG laser. Dong-Gyu Ahn and Kyung-Won Byun further investigated the optimal cutting condition at which the quality of cut section was good and high cutting efficiency was obtained. Arif et al. investigated heat transfer characteristics of the cut material developed by the laser cutting of the Inconel 625 using three-dimensional finite element methods.

Laser turning:

Khan et al. carried out wet finish turning of solution treated and aged Inconel 718 super-alloy with low grade (50% CBN content) PCBN tool in two geometric configuration. It was concluded that flank wear was the main failure mode in both cases of inserts (C-type & round). While optimizing the machining parameters of turning process of IN 718 under dry conditions, it was found more than 25% improvement in surface finish and MRR increased by approximately 800% compared to conventional machining processes [17]. Bhatt et al. studied the performance of uncoated and coated carbide tools with three different types of coatings in finish turning of Inconel 718 in which they found that at low speed of 50 m/min adhesive and abrasive wear were the dominant wear mechanisms for uncoated WC (K313) and single-layer (TiAlN) PVD coated tool, their main mode of failure at these speeds being flank wear and crater wear. Bushlya et al. carried out high speed turning of Inconel 718 with coated (TiN) and uncoated low grade PCBN tools. They observed that in the experimented speed range of 250–350 m/min intensive cratering was the main tool failure mode.

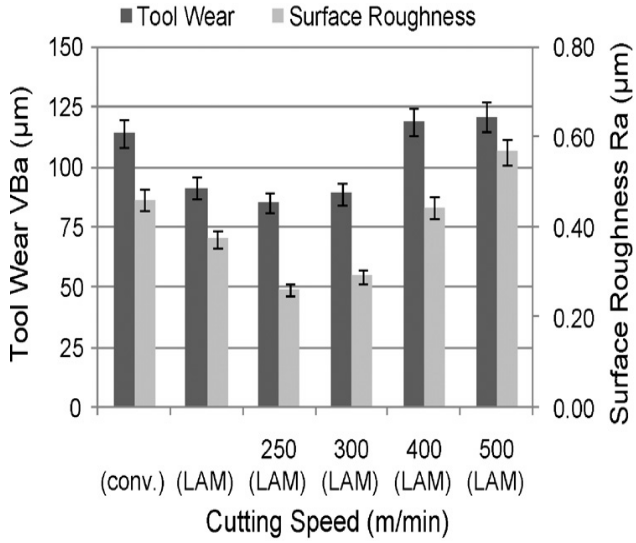

Fig.12:Effect of cutting speed on flank wear and surface roughness for conventional machining and LAM, feed = 0.25 mm/rev and DOC = 0.25 mm [17]

Laser metal deposition (LMD):

C Y Kong used LMD to find low heat input and high rate deposition in Inconel 718. A relatively fast deposition rate of 240 g/hr. was achieved in this work despite a low heat input parameters being used. Directionally solidified components can be prepared or repaired by metal deposition when appropriate processing strategy is followed, especially if the laser scanning direction is identical for the deposition of all layers [26].While investigating the LMD process in case of IN625 wire, it was found that energy per unit length of track and wire deposition volume per unit length of track significantly influence both the deposition process characteristics and the track geometrical characteristics. Processing conditions at which a combination of favorable single track properties including low contact angle (<80◦), dilution ratio ranging between 5% and 13% and high surface quality was being presented [27].

III. CONCLUSION

This study relates to the laser processes used for machining Inconel alloys. As the demand from the manufacturing sector is increasing, the other Inconel alloy types i.e. Inconel 750 and x-750 must be also be investigated for their machinability using laser. To make the use of Inconel more economically, research works can be done to properly validate powder recycling methods of Inconel alloys.

Most of the research works have been done to optimize the process parameters. Further research works can be done to develop simulation models to analyze the mechanical strength of Inconel alloys.

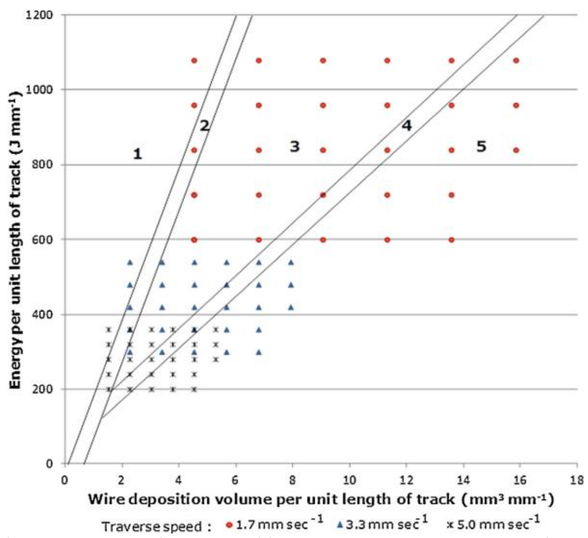

Fig.13:A process map for Inconel 625 wire laser deposited tracks. [27]

Table.1 Effects of alloying elements on Inconel

Alloying elements	Characteristics
Nickel	Improves strength, resists oxidation and corrosion
Silicon	Improves strength and wear resistance
Chromium	Gives resistance to oxidation
Molybdenum	Improves resistance to corrosion and provides strength
Iron	Controls thermal expansion
Carbon	Provides corrosion resistance and enhances strength
Aluminum	Resists oxidation, chlorination and carburization
Titanium	Promote age hardening and resists corrosion
Copper	Improves resistance to reducing acids.
Cobalt	Strengthens the alloy
Manganese	Reduces brittleness and increases hardenability
Boron	Increases hardenability
Phosphorus	Increases strength and hardness
Sulphur	Increases machinability
Niobium	Increases yield strength

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