ON LASER ASSISTED MACHINING OF INCONEL 718

**ABSTRACT**

Laser assisted machining (LAM) can improve the machinability of materials by locally

heating the material prior to its removal. The work presented here is a study of the laser assisted machining of Inconel 718 (NiCr19FeNb at 46 HRc) with ceramic insert. The tests have shown a reduction in the cutting force, and have highlighted the impact of laser assistance on the integrity surface (roughness, appearance, residual stress) and the tool life.

Also , It not only efficiently reduces the cutting force during the manufacturing process but also improves the machining characteristics and accuracy with regard to difficult-to machine materials. The prediction of relative deformations between the cutting tool and workpiece is important to improve the accuracy of machined components. And in the paper , the deformation errors caused by thermal effects in the laser-assisted machine tool using finite element method are also discussed.

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**INTRODUCTION**

**INCONEL 718 -**

INCONEL alloy 718 (UNS N07718/W. Nr. 2.4668) is a high-strength, corrosion resistant nickel chromium material. It is nickel – based super alloy. It have good balance

between corrosion and oxidation resistance. The Inconel provides good mechanical properties. The Inconel is suited for directional solidification casting but can also be used for conventional or single crystal casting techniques. It is well suited for the hot section components such as blades, vanes and ring segments for gas turbine engines. It can be used with various thermal barrier coatings. It also have a very good material strength at high temperatures. These properties permit their use in components for gas turbine engines where the retention of excellent mechanical properties at high temperatures is required. Hot section components include vanes, rotating blades and ring segments.

The ease and economy with which INCONEL alloy 718 can be fabricated, combined with good tensile, fatigue, creep, and rupture strength, have resulted in its use in a

wide range of applications. Examples of these are components for liquid fueled rockets, rings, casings and various formed sheet metal parts for aircraft and land-based gas turbine engines, and cryogenic tankage. It is also used for fasteners and instrumentation parts.

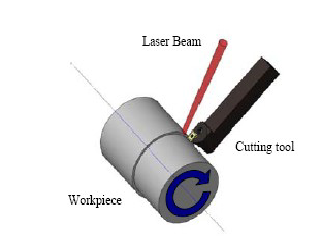
**LASER ASSISTED MACHINING -**

Laser Assisted Machining is a high temperature cutting process using a laser beam as the heat source . The principle of the process is to reduce the cutting force necessary to machine the material by increasing the temperature to the point where the strength of the material is reduced . Indeed at high temperature, the specific cutting energy is weak, which improves workability. General illustration is shown in the figure.

The main purpose of LAM is not to cut the material but to provide better and easy

environment for machining operation.

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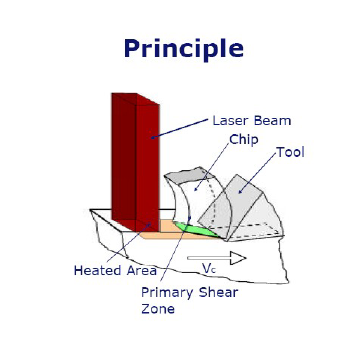
This fig. Illustrates **General Concept of Laser Assisted Machining**

**Working Principle -**

Laser Assisted Machining (LAM) is a new and innovative way of machining hard-towear

materials, which are difficult to machine using conventional methods. LAM combines

laser technology with traditional machining methods such as turning and milling. The laser is used as a heat source with the beam focused on the unmachined section of the workpiece directly in front of the cutting tool . The addition of heat softens the surface layer of the material, so that ductile deformation rather than brittle deformation occurs during cutting.



In above figure the main Principle of Laser Assisted Machining is described.

**REQUIRMENT OF LAM IN INCONEL 718 MACHINING -**

Inconel is a difficult metal to shape and machine using traditional techniques due to rapid work hardening. After the first machining pass, work hardening tends to elastically

deform either the workpiece or the tool on subsequent passes. For this reason, age-hardened Inconel 718 is machined using an aggressive but slow cut with a hard tool, minimizing the number of passes required. In order to increase productivity certain types of ‘assistance’ can be used to facilitate the cut. It has already been shown that LAM makes it possible to machine high strength alloy like Inconel 718.

Inconel does not change its mechanical properties even in high temperature .Hence, conventional machining (CM) of Inconel is slow and inefficient because only slow cutting speeds can be used. In order to increase productivity certain types of ‘assistance’ can be used to facilitate the cut. It improves workability by decreasing the cutting forces and byincreasing the tool life. This process is currently the only process able to machine very hard materials.

**USING LAM WITH CONVENTIONAL METOD**

Traditional methods of machining hard-to-wear materials include, grinding or diamond machining which accounts for 60%-90% of the final cost of the product Another method used is hard turning, where cutting speeds are increased greatly and a cubic boron nitride (CBN) tool is used. At these high speeds friction heat anneals the material directly in front of the cutting tool, which is then removed by the tool itself, leaving the machined surface unaffected. However CBN tools are expensive and it is estimated that tooling costs are very high.

Also it is seen that Direct laser machining has also been researched as a means of shaping hard materials. However it involves melting or evaporating the material, which can cause surface cracks and undesirable changes to the surface microstructure. Therefore, Laser Assisted Machining is very useful in case of Inconel 718.

**Various machining parameters -**

The following variables are considered while machining.

These parameters are considered as per recommendation of CeTIM ( Center for Technology & Innovation Management) for the insert used.

· Cutting speed – It is kept as Vc = 220 m/min.

· Feed – 0.18 mm/rev.

· Depth of cut – Ap = 1.5 mm.

· Material removal rate - 59.4 cm3.min-1

· Laser distance from cutting tool – Approximately 5 mm.

· Laser power - 0 Watts (for conventional machining), 1500 Watts

· Insert – CC670 Ceramic Insert (Sandvik) ref. RNGN 090300

The three components of the cutting force, the surface integrity (roughness, residual

stresses), and the tool life were measured for each test.

A new cutting edge was used for each test.

**Cutting fluids -**

Almost any cutting fluid, or none, can be used in machining Inconel. In many applications,Inconel respond well to ordinary sulfurized mineral oil; sulfur imparts

improved lubricity and anti weld properties. If the temperature of the oil and workpiece

becomes high enough during machining to cause brown sulfur staining of the work, the stain can be readily removed with a cleaning solution of the sodium cyanide or chromic-sulfuric acid type. This should be done before any thermal treatment, including welding, because during further exposure to high temperature the staining may cause inter granular surface attack. To avoid inter granular corrosion, the parts should be immersed in cleaning solution only long enough to remove the stain. High-speed machining operations that create high temperatures might preclude the use of a sulfurized oil because of sulfur embrittlement of carbide tools. (Many sintered carbides have a nickel or cobalt matrix that is sensitive to sulfur attack at high temperature.) However,flooding the cutting area with cutting fluid generally cools the tool enough to avoid breakdown of the carbide bond.

Water-base fluids are preferred in high-speed turning, milling, and grinding because of their greater cooling effect. These may be soluble oils or chemical solutions. Except for grinding, which depends almost entirely on cooling and flushing, some chemical activity is always desired and is generally provided by chlorine, amines, or other chemicals. For slower operations, such as drilling, boring, tapping, and broaching, heavy lubricants and very rich mixtures of chemical solutions are needed. Oils should be used when drilling nickel 200 and Inconel X-750. In the drilling and tapping of small-diameter holes and in other operations in which lubricant flow and chip flushing are restricted, solvents will improve performance. These less viscous fluids can be used alone or can be used for diluting mineral and lard oils. A cutting

fluid of the spray-mist type is adequate for simple turning operations on all alloys.

**Temperature effects** -

Laser assisted machine tool performs the localized heating and cutting process

simultaneously. So, the heats generated by localized heating process as well as the cutting process are conducted into cutting tool. In order to predict deformation errors, the heats from t he two heat sources have to be analyzed simultaneously and thermal distortion have to be calculated. And we have to judge thermal distortion due to heat generated bye Laser Beam. The results can be used to increase the cutting accuracy by compensating thermal distortion prior to laser-assisted machining.

**Tool Material:**

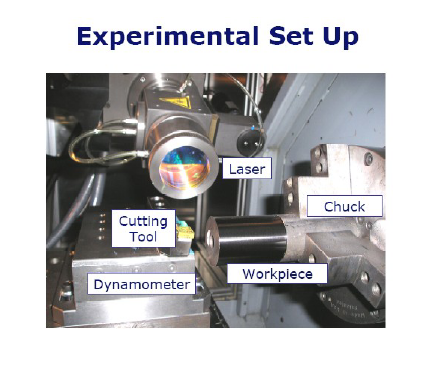
Carbide tools permit the highest cutting rates are recommended for most turning

operations involving uninterrupted cuts. Cast alloy tools are recommended for tuning group A alloys at optimum cutting rates. As with carbide tools, interrupted cutting is not include in this recommendation. High-speed steel tools should be used for interrupted cuts such as occur in the roughing of an uneven surface. They are also used for finishing to close tolerances, finishing to the smoothest surfaces, and cutting with the least work hardening.

**Experimental equipment -**

A numerically controlled lathe (REALMECA RT-5) equipped with a 2.5 kW ROFIN

YAG laser was used in this work. The laser nozzle can be controlled using three translations and two rotations. A numerical control system (NUM 1060) allows the control of the seven independent degrees of freedom. The high power laser beam is delivered through a fiber optic cable to the lathe chamber, where it is focused on the workpiece surface. During machining, a gas under pressure (air) is forced through the laser nozzle to protect the focusing lens from being damaged by chips. Three components of the cutting force are measured by a Kistler piezoelectric dynamometer.

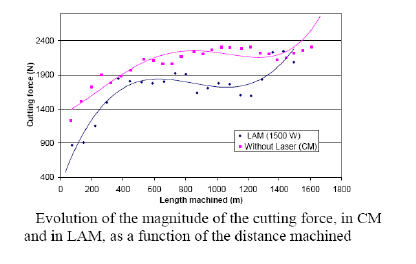
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**RESULTS OBTAINED -**

**1 ] Cutting force -**

The figure below shows the evolution of the magnitude of the cutting force as a

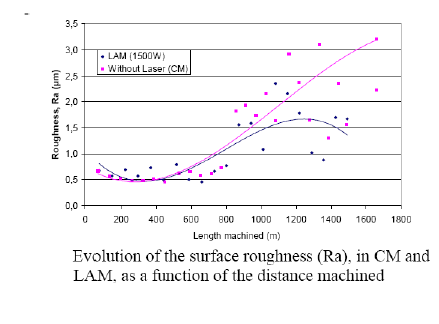
function of the distance machined for both conventional machining and LAM (1500 Watts). The cutting force in LAM is lower than in CM. Depending on tool wear, the reduction in the cutting force in UAL s between 40% and 20%.

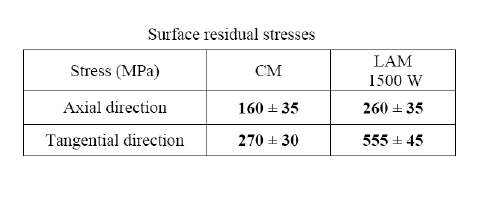


**2 ] Surface Integrity -**

The surface integrity was quantified by the measurement of surface roughness (three criteria: Ra, Rmax and Rz), by the determination of surface residual stresses and by

examination of the cut surface with a scanning electron microscope (SEM). The three roughness criteria show the same trend. Consequently only the Ra criterion is presented in figure It can be seen that the evolutions of Ra, in CM and LAM, are similar up to a machined distance of approximately 800 m. After this distance, the roughness is lower and less dispersed for LAM. For conventional machining after approximately 800 m, the roughness increase significantly and the data is widely scattered (scratches due to chips). The analysis of residual stress was performed using a PROTO X-ray diffraction machine. The following table summarizes the values of residual stress at the surface for the two types of machining.



These values indicate that these cutting parameters result in positive or tensile residual stresses in both directions. In addition, LAM generates higher stresses due to thermal effects of laser heating. These values confirm the results obtained in other materials.

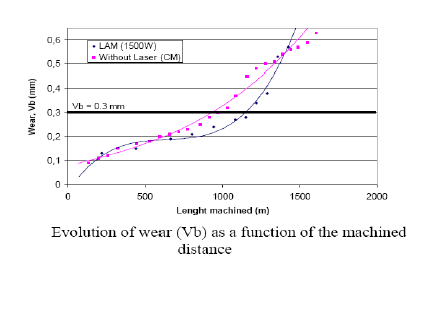
**3 ] Tool wear -**

The evolution of the wear on the clearance face, Vb, is shown in figure 8, for the two

types of machining, as a function of the machined distance. The evolution of the clearance wear is different for machining with and without laser assistance. In conventional machining clearance wear increases approximately linearly, while for LAM three areas of change are visible.

In LAM, at the beginning of machining, up to about 400 m, the wear increases rapidly (run-in). Then between about 400 and 1000 m, the wear is relatively stable in LAM. By contrast, from 1000 m the degradation of the tool is greater in LAM with a very rapid increase in clearance wear.

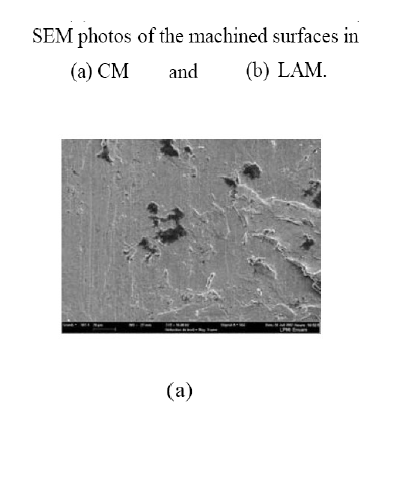
For a maximum wear criterion set at Vb = 0.3 mm (ISO standard), the tool life is 4min 25sec in CM and 5min 40sec in LAM.

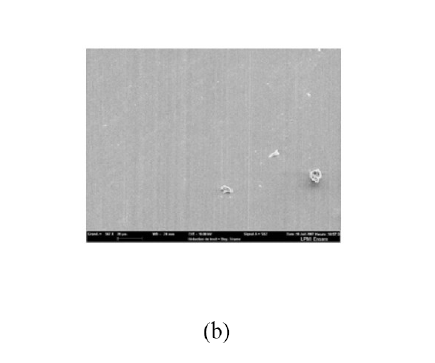


**Surface Finishing** -

After machining process done , the machined surfaces were observed with a Scanning

Electron Microscope (SEM). The figure below shows pictures of the machined surfaces in Conventional Machining (a) and LAM (b).





These photos (taken at the same magnification) demonstrate that the surface quality is considerably higher in LAM than in CM. In CM, the surface appears to be torn and dark spots, evenly distributed over the machined area, can be observed.

Electron Diffusion Spectrometer (EDS) analyses were conducted to determine the nature of these dark spots. The EDS analyses show that all of the dark spots are caused by pollution of the surface by the tool insert. The presence of these elements (silicon, nitrogen, oxygen and aluminum) corresponds to a material deposit from the tool insert. This phenomenon is only visible on the conventional machined specimens. The machined parts in LAM demonstrate no such pollution.

**Advantages**

· Reduction of cutting forces-primarily affected by the cutting speed, laser power density, and

distance between the tool and laser beam. The lower cutting force at higher cutting speed in LAM means that it is possible to increase the Inconel removal rate at the same lathe power

· Lower dynamic forces due to the continuous plastic deformation during chip formation,

leading to reduction of chatter.

· Less sharp segmented chip produced at high cutting speed because of lower heat

generated at the primary shear zone.

· Lower hardness near the machined surface compared with conventional cutting due to

the lower shear deformation.

· Smooth surface finish because of lower dynamic cutting force.

**Conclusion**

In this study, on the laser assisted machining of Inconel 718 has highlighted significant comparison between the use of Conventional Machining and Laser Assisted Machining with combination of Conventional machining. Also , The prediction of relative deformations between the cutting tool and workpiece is important to improve the accuracy of machined components using Finite Element Method (FEM).

Tests have shown that, LAM significantly reduces the cutting force (up to 40%). The

integrity of the machined surface, in terms of roughness, is not improved with the use of

ceramic inserts in LAM compared to CM. Ceramic inserts allow a very good performance during the laser assisted machining, In fact, the life of ceramic inserts in LAM increase by 25% compared to the life in CM.

In experiment its also found out that , the peak temperature is increased from the mean temperature due to cutting thermal effects during cutting. And the higher mean temperature is defined, the lower cutting force is occurred because the workpiece is softened by laser heating. Also , if the closer location from the laser heating is defined, the higher deformation errors are occurred. Thus, the location from the laser heating is important for deformation errors of the cutting tool in laser-assisted machining. Therefore , the results can be used to increase the cutting accuracy by compensating thermal distortion prior to Laser Assisted Machining.

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