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Pulsed laser-assisted machining of Inconel 718 superalloy

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Nickel-based superalloys including Inconel 718(IN718) are widely used in aerospace industries due to their superior high temperature strength, toughness, and corrosion resistance. These alloys are difficult to machine mainly because of their low thermal conductivity and high work hardening rate, which cause steep temperature gradient and high cutting forces at the tool edge. The application of laser assisted machining is the subject of many new researches since shear forces; surface coarsening and tool wear are reduced. The aim of this investigation was to evaluate laser assisted machining behavior of a 718 Inconel superalloy from the view point of machining specific energy, surface roughness, tool wear and chip appearance. Experimental apparatuses used included optical and scanning electron microscopy, spark emission spectroscopy, and EDS analysis. The results indicated that increasing the temperature to about 540 °C just ahead of primary shear zone, can result in 35% reduction of machining specific energy, in comparison with conventional machining. Furthermore, surface coarsening and tool wear were reduced by 22% and 23% respectively. Flank wear was the main deteriorating factor on cutting tools during laser assisted machining. SEM micrographs indicated that increase in temperature has no noticeable effect on finished workpiece surface. Analysis of variance obtained from regression analysis indicated that frequency of laser beam has the most influential effect on temperature. The optimum conditions for laser assisted machining of 718 superalloy is suggested as follows: 80 Hz frequency, 400 W power, 24 m/min cutting speed, and 0.052 mm/rev feed rate along with 540 °C temperature, 2.51 J/mm^2 machining specific energy and 130 N cutting force.

1. Introduction

Superalloys retain their strength at elevated temperatures and have low coefficient of thermal conduction, resulting in poor machining behavior [1,2]. Modifying the alloy content and/or applying heat treatment can have adverse effects on mechanical properties and generally have no positive effect on their machinability. As a result, excessive tool wear, built-up edge formation and poor surface finish occur during conventional machining of such alloys [3]. Laser assisted machining (LAM) is a new technique of improving machining characteristics of many difficult to cut materials by reducing the cutting forces, finished surface roughness and cutting tool wear [4].

In laser-assisted machining (LAM), which is well suited for machining superalloys, the workpiece is subjected to localized heating through a focused laser beam ahead of primary shear zone on the uncut workpiece surface [5]. This heating improves the machinability through softening the workpiece material and reducing tool wear, without causing subsurface damage [6]. LAM will only become viable on an industrial scale if it can be proved versatile in different domains of activity. It has already been shown that LAM makes it possible to machine high strength metals like Ti6Al4V [7,8], Inconel 718 [9], graphite iron [10], AISI D2 tool steel [11] or metal matrix composites [10] and ceramics [12,13]. The benefits of heating Inconel 718 prior to the material removal with a conventional cutting tool have been demonstrated by Rajagopal et al. [14], Novak and co-workers [15,16], and Leshock et al. [17]. These exploratory investigations demonstrates optimization of surface roughness, decrease in specific cutting energy, and an increase in tool life in thermally assisted machining of Inconel 718. Attia et al. [18], have shown that when using ceramic tools, increasing cutting speed up to 300 m/min, results in temperature rise, lower strength and surface roughness when LAM is used. Panjehpour et al. [19] using pulsed Nd:YAG laser beam illustrated that, increasing laser power up to 425 W reduces tool wear and surface roughness. Pooladsaz et al. [20] also used pulsed Nd:YAG laser assisted technique when machining Titanium alloy and showed a marked reduction in cutting forces and surface roughness.

It should be mentioned that the majority of research carried out using LAM, have utilized CO_2 laser beam as a heat source. However, due to its low absorbing nature, especially in machining

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superalloys, high powers may be required for efficient machining. CO_2 lasers also have a wavelength of 10 μm which don't pass through optical fiber. Nd:YAG laser facility with 1 μm wavelength can provide a good source of heat for softening the work material and can be used very effectively for chip removal and machining superalloys. Although there were some studies about Nd:YAG laser assisted machining [15,21], but, there is no comprehensive study on pulsed Nd:YAG laser assisted machining of superalloys and more study is required to establish a conclusive results for better machinability of such alloys. At the same time, there are potential advantages when pulse laser beam is used, including better localized heating which has a less effect on material"s substrate and better control of varieties. Of course, there are some drawbacks when using pulse laser beam, for instance the control and processing variables are more complex. In the presented study, with proper experimental design, effects of processing variable were considered.

The goal of this study is to investigate the influence of Nd:YAG laser parameters on machining characteristics of In718 superalloy and compare the results with its conventional machining. Furthermore, the influential effects of laser parameters and cutting conditions on temperature distribution, chip formation, specific cutting energy, surface roughness, tool wear, surface and subsurface integrity are examined.

2. Experiments

2.1. Experimental setup

A Nd: YAG pulsed laser, Model IQL-20 with a maximum average power of 750 W and wave length of 1.064 nm was used for laser assisted machining tests. The frequency range varied between 1 and 250 Hz with pulse duration of 0.2–25 ms, and pulse energy of 0–40 J. Compressed air of 4 bars was used to protect the laser lens from excessive heat and chip fragments. Machining was conducted on a 2 HP Shimato lathe machine, model CO636A. The laser head was installed on a fixture connected to the lathe support and was set at the angle of 60° circumferentially on workpiece surface ahead of the cutting tool. The beam was targeted by a fiber optic cable through a lens with spot size of 3.3 mm.

The diameter of the workpiece was 25 mm with hardness of 26 HRC. Prior to each LAM test, the workpiece surface was sandblasted. About 40 mm length of the material was machined for each experiment. The cutting insert used was a cemented carbide tool of the type AC520U (i.e. SNGA120408) which has a tool nose radius of 0.8 mm. The cutting insert was mounted on a standard tool holder (i.e. MSBNR 20*20) with rake angle set at −5°, side cutting edge angle 15°, main cutting edge angle 75° and relief angle of 6°. A schematic experimental setup is shown in Fig. 1.

In all experiments, the cutting force was measured by strain gauges (i.e. TM-FLA-5-11) installed on the tool holder. A Wheatstone bridge and TM1020 module signal were used to measure strain changes in the gauges. Software was calibrated by applying gauge factors (i.e. 2/11 ± 1%). Temperature measurement was performed using ST-8869 infrared thermometer with temperature range of −50 to1600 °C.

2.2. Characterization

The Germany Zeiss scanning electron microscope (SEM) was used to study the microstructure and tool wear features. It was equipped with EDS model TESCAN made in Czech for semi-quantitative analysis of elements at a certain point. Voltage was applied about 15 kV and the working distance set at about 17.4 mm.

Vickers hardness measurements were carried out using hardness tester model ZWICK. The load in all hardness tests was equivalent to 100 g. The average hardness values at four points were recorded, with ±1 accuracy.

The samples were mounted in Bakelite and polished using standard metallographic techniques. Etching solution was 10% Oxalic acid. Also, tool wear measurements were in accordance with ISO-3685 [22].

2.3. Laser heating experiments

To reach the appropriate temperature range in the workpiece near the primary shear zone, preliminary heating experiments were performed. The combination of machining parameters (i.e. without material removal) and laser parameters were considered for the experiments. Pulse laser variables, included laser mean power and pulse frequency. The machining parameters such as cutting speed and feed rate were also considered. The position of temperature measurements on the material surface along the center line of the workpiece ahead of primary shear zone is shown in Fig. 2. In order to use the non-contact thermometer the emissivity value of sandblasted workpiece was needed. The accuracy of the thermal instrument was 1% with a response time of 100 ms. When P1 in Fig. 2 was near the measuring temperature point, the temperature increased rapidly and decreased with passing through it.

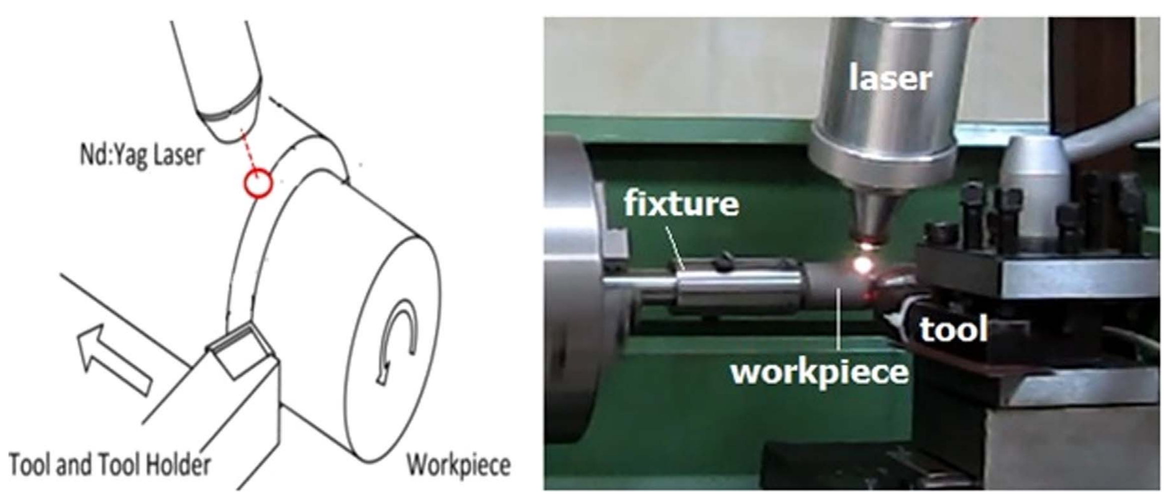

Fig. 1. LAM experimental setup with Nd:YAG pulsed laser.