Available online at www.sciencedirect.com
ScienceDirect
International Journal of Machine Tools & Manufacture 47 (2007) 1139–1150
INTERNATIONAL JOURNAL OF MACHINE TOOLS & MANUFACTURE DESIGN, RESEARCH AND APPLICATION
www.elsevier.com/locate/ijmactool

Characterization of a hybrid laser-assisted mechanical micromachining (LAMM) process for a difficult-to-machine material

Ramesh Singh, Shreyes N. Melkote*

George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0405, USA

Received 26 April 2006; received in revised form 18 August 2006; accepted 4 September 2006
Available online 3 November 2006

Abstract

Mechanical micro-cutting is emerging as a viable alternative to lithography based micromachining techniques for applications in optics, semiconductors and micro-mold/dies. However, certain factors limit the types of workpiece materials that can be processed using mechanical micromachining methods. For difficult-to-machine materials such as mold and die steels or ceramics, limited cutting tool/machine stiffness and strength are major impediments to the efficient use of mechanical micromachining methods. In addition, at micron length scales of cutting, the effect of tool/machine deflection on the dimensional accuracy of the machined feature can be significant. This paper presents experimental characterization of a novel hybrid laser assisted mechanical micromachining (LAMM) process designed for 3D micro-grooving that involves highly localized thermal softening of the hard material by focusing a solid-state continuous wave laser beam in front of a miniature cutting tool. Micro-scale grooving experiments are conducted on H-13 mold steel (42 HRc) in order to understand the influence of laser variables and cutting parameters on the cutting forces, groove depth and surface finish. The results show that the laser variables significantly influence the process response. Specifically, the mean thrust force is found to decrease by 17% and the 3D average surface roughness increases by 36% when the laser power is increased from 0 to 10 W. The groove depths are found to be influenced by the machine (stage) deflection and tool thermal expansion, which affect the actual depth of cut, in the presence of laser heating. In particular, it is found that the accuracy of groove depth improves with laser heating. Explanations for the observed trends are given.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: Micromachining; Laser assisted; Micro-grooving; Hard material

1. Introduction

There is growing need for effective ways to manufacture parts with micro- and meso-scale features that have applications in the fields of optics, semiconductors and micro-molding of plastics. In response to this demand, mechanical micro-cutting (e.g. micro-grooving, micro-milling) is emerging as a viable alternative to lithography based micromachining techniques. Lithography based methods are primarily limited to semiconductor materials like silicon and are generally not suitable for creating free form 3D shapes. They are also cost-prohibitive in many cases [1]. In contrast, mechanical micromachining methods such as micro-grooving/milling are capable of generating 3D free-form features with micron level accuracy [2,3]. Despite potential advantages, practical use of mechanical micromachining is limited by the properties of the work-piece and tool material. In particular, very low tool stiffness and bending strength limit the utility of mechanical micromachining, especially for hard-to-machine materials such as mold/die steels. At micro/meso-length scales of cutting, the effect of tool and machine (e.g. motion stage) deflections, arising from the increased cutting forces, on the dimensional accuracy can be significant. One approach to address this situation is to employ the thermal softening ability of a laser source to heat the material during micro-cutting.

At the conventional scale, laser assisted mechanical machining has been investigated for processing

---

*Corresponding author.
E-mail address: shreyes.melkote@me.gatech.edu (S.N. Melkote).

0890-6955/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2006.09.004

hard-to-machine ceramics. Laser assisted hot machining of ceramics was initially suggested by König and Zaboklicki [4]. Laser assisted mechanical machining of silicon nitride has been studied extensively [5,6]. Laser assisted mechanical machining of other ceramics such as sintered mullite and magnesia-partially-stabilized-Zirconia have also been reported [7,8]. These studies focus on material removal mechanisms, temperature prediction, wear modeling and evaluation of surface integrity. Plasma assisted milling of super alloys has been reported at the macro scale [9]. Kaldos and Pieper [10] have reported a two-step procedure for die making that consists of roughing by conventional milling followed by finishing with a 100 W Nd:YAG laser.

Pure laser micromachining is primarily limited to ablation processes. The use of ultra-short pulsed (e.g. femtosecond) UV lasers for pure laser micromachining has drawn the attention of researchers in the past few years. These laser systems have been successfully applied to micromachining of masks for lithography, MEMS, photonics, coronary stents and dental surgery [11–15]. Typical etch rates for nanosecond and femtosecond laser vary from 1 to 0.032 μm/pulse. The typical feature size is between 3 and 20 μm [16]. The typical material removal rates are of the order of 0.1 mm^3/min for deep drilling of hardened steel and 1 mm^3/min for grooving in PMMA [17,18]. In contrast, for pure mechanical micromachining a material removal rate of 25 mm^3/min has been reported [19]. Although ultra-short laser micromachining can give fine detail, it is a slower process and much better suited for processing thin films. In addition, generating a sculpted surface with complex 3D features can be difficult with these systems. A logical solution to this limitation is to develop a hybrid process that combines the beneficial aspects of laser heating and 3D mechanical micro-cutting.

However, no detailed studies have been reported on laser assisted mechanical machining of hard materials at the *micro-scale*. Initial investigations by Singh and Melkote [20,21] revealed evidence of laser softening in AISI 1018 and hardened H-13 steels. Recently, Jeon and Pfefferkorn [22] have studied the effect of laser preheating on micro-end milling of metals (Al 6061 T6 and 1018 steel). They however used a conventional milling machine and millimeter sized 100 W Nd:YAG laser beam. Hard-to-cut materials were not studied in their work.

The work described in this paper builds on previous work by the authors [20,21] to further understand the process. The present paper describes the experimental setup and characterization of a laser assisted mechanical micromachining (LAMM) process for 3D micro-grooving of a hard mold steel with a particular focus on the cutting forces, groove depth and surface finish.

2. Basic approach

The basic approach consists of combining a low-power (0–10 W) continuous wave fiber laser with a mechanical micro-grooving process. The laser beam is focused in front of a miniature cutting tool to soften the workpiece material just ahead of the cutting tool thereby lowering the forces required to cut the material. Once modeled and understood, local thermal softening can be controlled and confined to the material volume being removed by the tool thereby minimizing the thermal damage. Preliminary work [20,21] has shown that thermal softening and consequently lower cutting forces are observed under certain, but not all, conditions. Initial investigation of the LAMM process applied to 1018 steel [20] revealed that the effect of thermal softening can be offset by thermal expansion of the tool, which results in an increased depth of cut. Other factors such as tool/machine deflections can also alter the nominal depth of cut. Hence, the expected decrease in cutting force is not observed under all conditions. To further understand the LAMM process, a design of experiments method is employed in the present paper to investigate the effects of laser variables and cutting parameters on the cutting forces and surface finish in micro-cutting of heat treated mold steel. The effects of tool/machine deflections and tool thermal expansion on the depth of cut are also evaluated.

3. LAMM setup for 3D micro-grooving

A schematic of the first generation LAMM setup for 3D micro-grooving is shown in Fig. 1. A 10 W solid-state ytterbium fiber laser (Model YLM-10) is integrated with a precision 2-axis motion control stage (Aerotech ATS-125). The positioning resolution of the stage is 0.1 μm with 1 μm accuracy per inch of axial travel. The only moving component is the workpiece, which is mounted on the stage. All other components including the tool holder and laser are stationary. As such, the machine is capable of generating features on the order of a few microns. The laser beam is emitted from a 7 μm diameter single mode fiber through a collimator. The beam has a near infrared wavelength of 1064 nm. A red aiming beam that is collinear with the laser beam allows the laser beam to be approximately spotted. The collimator and focusing lens are mounted on a small *Y–Z* stage mounted on the carriage of a precision slide. The distance of the focusing lens from the workpiece can be adjusted to vary the spot size of the laser. The focal length of the lens used in the current study is 250 mm, which yields a laser spot diameter of about 70 μm. The laser controller is used to modulate the laser power. The components of the setup are mounted on an aluminum base plate and the entire setup is placed on a vibration isolation table.

The setup is instrumented to measure the cutting forces using a piezoelectric force dynamometer (Kistler Minidyne® 9256C2). The tool holder is mounted on the dynamometer and holds a micro-grooving tool of 300–500 μm cutting width. The cutting tool material used in this study is tungsten carbide (WC) coated with TiAlN. The rake angle is 0°, the back clearance angle is 2.5° and the side clearance angle is 5°. The workpiece is fixed to the

Download English Version:

https://daneshyari.com/en/article/782056

Download Persian Version:

https://daneshyari.com/article/782056

Daneshyari.com