Picosecond laser fabrication of micro cutting tool geometries on polycrystalline diamond composites using a high-numerical aperture micro scanning system

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ABSTRACT

The generation of microsized components found in LEDs, watches, molds as well as other types of micromechanics and microelectronics require a corresponding micro cutting tool in order to be manufactured, typically by milling or turning. Micro cutting tools are made of cemented tungsten carbide and are conventionally fabricated either by electrical discharge machining (EDM) or by grinding. An alternative method is proposed through a laser-based solution operating in the picosecond pulse duration whereby the beam is deflected using a modified galvanometer-driven micro scanning system exhibiting a high numerical aperture. A micro cutting tool material which cannot be easily processed using conventional methods is investigated, which is a fine grain polycrystalline diamond composite (PCD). The generation of various micro cutting tool relevant geometries, such as chip breakers and cutting edges, are demonstrated. The generated geometries are subsequently evaluated using scanning electron microscopy (SEM) and quality is measured in terms of surface roughness and cutting edge sharpness. Additionally, two processing strategies in which the laser beam processes tangentially and orthogonally are compared in terms of quality.

Keywords: micro cutting tools, diamond, 2.5D ablation, picosecond laser, scan system, chip breaker, cutting edges

1. INTRODUCTION

1.1 Processing of tool geometries

As outlined by Rodriguez [1], cutting tool geometries can be fabricated using a broad range of processes differentiated according to the utilized energy source: mechanically (e.g. ultrasonic, water jet), thermally (e.g. laser-, plasma- and electron beam) or chemically (e.g. electrochemical machining). Current tooling geometries, regardless of feature size, are predominately fabricated either mechanically by grinding or thermally by wire or disc electrical discharge machining (EDM). The limitations of these two conventional techniques are based on the fact that the former induces forces on the fabricated tool, and in the latter, electrical conductivity of the workpiece to be processed is necessary. Thermal effects on the diamond are ignored since it is assumed that it is effectively mitigated through the use of coolant. However, microcracks are introduced in the case of grinding or the grain is removed by melting the surrounding binder material in case of EDM. With respect to grinding, tool diameters Ø < 1 mm are increasingly difficult to manufacture, therefore tools with such dimensions are defined as micro cutting tools.

1.2 Micro cutting tools

It is often argued that for decreasing part size, the use of conventional machining techniques no longer becomes economical. According to Gower [2], for hole diameters Ø < 100 µm such as in the case in PCB drilling, the ability for tungsten carbide drills to generate such feature sizes are too expensive and wear quickly owing to their difficulty of being conventionally manufactured. This is because many characteristic features such as clearance angle, rake angle, microfeatures at chisel edge and diameter-to-length ratio are severely limited if non-existent. As a result, the direct fabrication of laser drilled holes become advantageous, e.g. $0.06/1000 holes as opposed to several $1/1000 holes.

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However, conventional machining techniques can be significantly advantageous or otherwise the only possibility compared to laser processes especially since a machining company only has to invest in the cutting tool as opposed to an ultrashort pulsed laser. Examples include the machining of optics, mirror finish machining, generation of threads and undercuts, high length-to-width ratio features found in EDM electrodes and high material removal rates. Here, ultrashort pulsed laser technology is limited if not incapable of fulfilling such demands. Hence, an alternative proposal is presented in this paper in which laser technology and a high-numerical aperture micro scanning system is used to fabricate micro cutting tool geometries. These geometries would then be subsequently used in machining operations. Figure 1 depicts three different approaches to fabricate an end product.

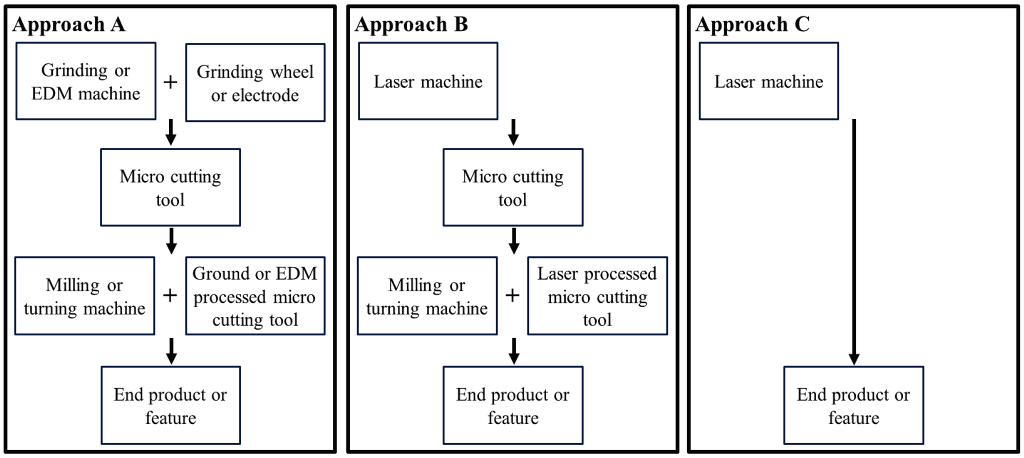

Figure 1. Different approaches and sequences needed to manufacture a product or feature.

This paper will follow approach B and will concentrate on picosecond laser processing of polycrystalline diamond composites, targeting micro cutting tool applications without the use of mask projection or other complex and expensive technologies. Additionally, no subsequent post-processing steps are taken in order to reach the final surface quality, i.e. no etching, electroplating or other special treatments.

2. METHODOLOGY

2.1 Experimental setup

The micro scanning system used is based on a galvanometer-driven scanhead, in which the deflected light rays pass through an optical arrangement to be imaged onto the input pupil of a microscope objective with a high numerical aperture. The system, described by Gottmann et al. [3], is mainly applied to the in-volume selective laser etching (ISLE) process typically on glass and sapphire.

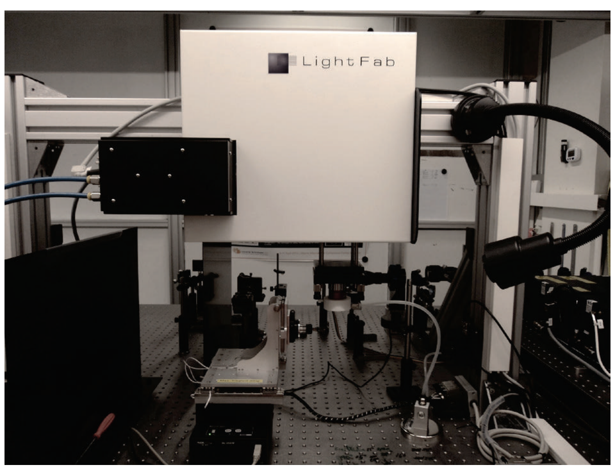

Figure 2. Experimental setup used to generate micro cutting tool geometries.