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A new manufacturing chain for ceramic shaping: sequential combination of milling and laser machining in green ceramic

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Abstract
The ceramic microcomponents have very interesting mechanical and thermal properties in an extreme environment such as a high temperature, a corrosive environment, etc. Unfortunately, the principal limitation of ceramic material usage is its shaping because of the brittleness of the material. In modern industry, the use of ceramic materials is still limited to particular applications.
MACHCERAM is a new manufacturing chain for ceramic shaping developed from powder synthesis to final machining which introduces a hybrid machining by combining the machining with a cutting tool and a laser machining. The Green Ceramic Machining (GCM) is carried out in this dedicated novel sub-hybrid platform. This combination allows to increase the productivity and repeatability, specifically thanks to the reduced laser spot size that allows to machine small features. The goal of this paper is to find the best combination between the tool diameter and laser machining in this manufacturing chain to reduce the machining time. The optimum is determined with the help of a Computer-Aided Manufacturing (CAM) software developed for the milling process by modeling the laser beam as a cutting tool. The machined result of the combination shows a 50 μm offset between both processes. In this stage production, thin walls of 200 μm break because the mechanical properties of the material are low. Surface integrity is also impacted with a different dimensional tolerance between both processes.

Green Ceramic Machining; Hybrid Machining; Ceramic; CAD/CAM

1. Introducion

Engineering ceramics offer numerous advantages in durability, hardness, biocompatibility, mechanical strength at elevated temperatures, chemical inertia compared to metals and engineering polymers. These characteristics allow to be very competitive in a wide range of engineering fields as aerospace, automotive, biological, electrical and chemical engineering. Unfortunately, the principal limitation of ceramic material is its shaping because of the material brittleness. The shaping of medium and large series is a process with a high cost and mainly poor reproducibility. The micro manufacturing of ceramic components is one of the technological challenges especially when complex shapes and micro features are required [1-3].
The beginning of the manufacturing of ceramic products is based on the powder preparation in which the ceramic powder is mixed with a polymer binder to improve the material ductibility by adding stabilizers to master the sintering. This binder ensures that a machinable blank can be obtained after compaction (uniaxial and isostatic). Finally, the blank is machined with a cutting tool before its sintering cycle which gives it the desired mechanical properties [1-3]. But, the machining with cutting tool can generate wall breakdown due to the contact between the tool and the material. MACHCERAM is a new manufacturing chain for ceramic developed from powders synthesis until final machining. In this case, the difference is a new step in the green machining with the technology of laser machining. The Dispersed Absorptive Solid Inorganic Material (DASIM) is added during the powders preparation to favour the laser ablation by limiting the risk of local sintering due to heat exchange [4].
The hybridization of both machining processes can be carried out in a subhybrid platform [5-6]. The subhybrid platform is a hybrid process which combines two similar technologies. The literature shows that this type of hybridization is already used in other materials in which the laser is used in the last step to deburr, polish and finish. The latter is mainly used to increase the miniaturization capacity [6]. Each process has its own computer-aided manufacturing (CAM). But hybrid machining means a CAM standardization to work in the same environment. The goal of this paper is to determine the optimal size of the cutting tool diameter for a microfluidic structure application. The hybrid machining results are compared between hybrid and laser machining on green ceramic.

2. Methodology

The methodology is to follow the CAD/CAM digital chain with the subhybrid platform on a microfluidic structure proposed by the literature [6-7] whitout the sintering step.

2.1. Computer-Aided Design (CAD)

The microfluidic structure studied is a microchanel with a thickness of 200 μm and a depth of 500 μm. The radii of curvature are 200 μm. This structure is machined inside a 6 mm x 5 mm area. The dimensional accuracy of components is of ± 1 mm, the position accuracy is of ± 5 mm and surface quality Rz inferior to 5 nm [6].

2.2. Computer-Aided Manufacturing (CAM)

The CAM software used to generate the G-CODE for the subhybrid platform is MasterCAM which is used for machining with a cutting tool. Laser machining is a non-contact machining process that generates a taper angle of 10° [8]. This laser source is modelled in the CAM sofware by a chamfered tool that allows to obtain a clearance angle of 10° with a tool diameter of 50 µm which corresponds to the spot diameter. To define the machining parameters, an analogy between the parameters is carried out (See Table 1). The determination of machining parameters is carried out experimentally to avoid initiation of micro-cracks or local sintering.

Table 1 Equivalence between the machining parameters

Milling		**Laser Machining**	
Tool diameter [mm]	0.3/0.5/0.8 /1/1.5/2	Spot diameter [µm]	50
Feed rate [mm/min]	2250	Scanning speed [mm/s]	1100
Cutting speed [m/min]	47	Laser power [W]	15
Radial depth of cut [%]	40	Hatching [%]	40
Axial depth of cut [mm]	0.5	Slicing [µm]	15

In the hybridization frame, the laser beam becomes a finishing tool. The optimal diameter of the cutting tool is therefore the roughing tool that allows to reduce the global machining time.

3. Results

Figure 1 shows the evolution of machining time in relation with the tool diameter by breaking down the machining time with the cutting tool and the laser machining time. An optimal machining time is detected when the tool diameter is 0.8 mm. The virtual time is around 50 s whereas the virtual time with the only laser is around 60 s. Before this optimal diameter, the machining time is longer with the risk of reaching the limits of the spindle capacity to ensure sufficient cutting speed.

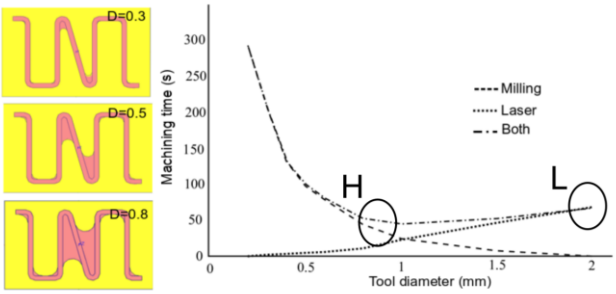
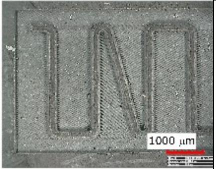
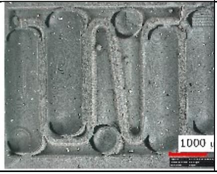


Figure 1: Optimization of machining time

Table 2 shows results for the hybrid and laser machining. A scale factor of 10 is visible between the real machining time and the virtual machining time but the tendency is similiar. In the case of laser machining alone, the wall thickness of 205 µm is obtained along the microchannel without breakdown. A depth of 495 µm is obtained by milling and a depth of 360 µm is obtained by laser machining. This significant difference with the target value of 500 µm shows that the abalation depth is not mastered. By contrast, a wall breakdown is visible when hybridization is applied because the contact of the tool with the brittle material generates an excessive force. In addition, the surface integrity of the machined part is not ensured. In fact, each process generates a different surface roughness. The arithmetic roughness is 1.4 µm for laser and 0.9 µm for milling.

Hybridization also requires a calibration of the two processes between them. Despite the optic calibration performed according to [9], an offset is still visible between origins of both processes of 50 µm in each direction. This shows that a calibration using an optical method is not sufficient.

Table 2 Comparison between full laser machining (L) and hybrid machining (H)

	Tool diameter [mm]	Machining results	CAM [s]	Real [s]
L			60	600
H	0.8		50	505

4. Conclusion

MACHCERAM is a new manufacturing chain for ceramic components. This technology allows the laser machining on a green ceramic despite the heat exchange that could lead to sintering. The major advantage of this technology is that it can be coupled in a subhybrid platform with a cutting tool which is the traditional method. A CAM software is used to model the laser and control this hybrid machining. This study allows to determine an optimal tool to be selected for a minimal machining time. A scale factor of 10 is noted between the virtual and the real machining times. The hybridization reduces machining time but surface integrity is impacted. The virtual ablated depth and the real depth are different. The modelled axial depth for laser ablation must then be improved to ensure a correspondence between the real ablated value and the theoretical value during the laser scanning. In addition, machining with a cutting tool increases the risk of wall breakdown. In perspective, a particular study on thin walls machined in a green ceramic must be carried out in order to improve the Design For Manufacturing (DFM).

5. Aknowledgements

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