Laser Micro Machining of material surfaces

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ABSTRACT

For high precision fabrication of fine structures and for making fine surface textures - a predefined finishing roughness on surfaces - several laser processing techniques are developed at TNO.

The laser micro milling technique is applicable to make blind holes, grooves and other programmed shapes. It is a self-adjusting technique applicable e.g. in the manufacturing process of high precision parts for the tool-making industry.
The removal of material is achieved by local and repeatedly evaporation of small quantities of material from the workpiece-surface. The ablation rate or milling rate is determined by the laser fluence, the powerdensity and the way the process is programmed. For circular and rectangular shapes recipes are developed, which can be combined for other shapes. A patent on this work, which is carried out in a Brite program* is in preparation.

An application of the laser surface texturing technique, by which a variety of finishing roughness reproducable can be achieved, is the making of predefined surface textures on metal moulds for duplicating the texture on plastics products.

A laser surfacing technique, which results in glazy layers on metal surfaces, with interesting properties will also be reported.

The processes described require lasers and deflection systems which parameters are of good repeatability and constancy; such equipment is available on the market. For the reported work a Nd-YAG laser processing machine is applied while short pulses with a high peak power and high powerdensities on the workpieces surface are required.

The technique described can be used for both metallic and ceramic materials.

* BRITE Contract NO. RI.IB.0129 UK (H)

1. INTRODUCTION

Laser Micro Machining is a self-adjusting ablation technique applicable in the manufacturing process of high precision parts e.g. the tool-making industry.
The removal of material is achieved by local and repeatedly evaporation of small quantities of material from the workpiece-surface using laser radiation. The ablation rate or milling rate and the heat input can accurately be controlled, making the technique suitable for the fabrication of very fine structures.

In comparison with other material processing techniques using lasers, there is a number of differences in efficient use of the laser energy and the intended result.
With surface treating e.g. steel hardening the material surface only has to be heated. With welding the material only has to be melted. With cutting the material has to be vaporized, melted or oxidised as efficiently as possible, removing the material through the cut.
With the micro-machining technique, making blind holes, the ablated material cannot be removed through the cut and may also not be deposited on the workpiece-surface.
Therefore a technique is developed where about 10% of the laser energy is used for the ablation itself and the remaining energy for regulating the process.

2. LASER MICRO MACHINING

A proper focussed pulsed laserbeam has to be scanned over the workpiece surface. A control program has to be used to adjust the relative position of the workpiece with respect to the scanning beam in order to get a shape.

The depth of the shape is determined by the position of the minimum beam diameter with respect to the ablated surface.

In figure 1 and 2, which are figures taken over from a Patent Application**, some aspects of the process are illustrated.

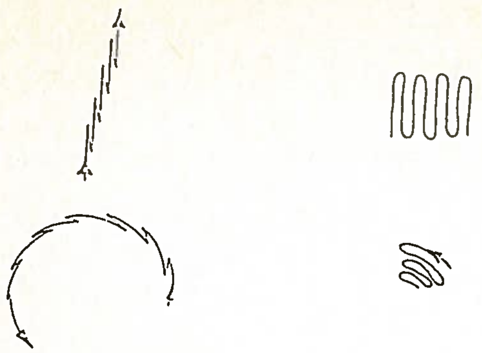


Figure 1 Recipes for some shapes

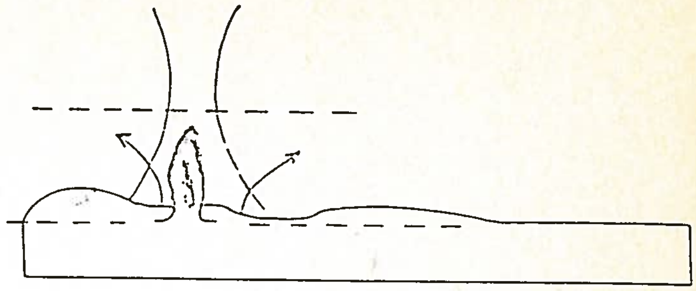


Figure 2 Self-adjusting flatness

Figure 1 shows recipes for a repeatedly relative scanning movement between laserbeam and workpiece achieving a local, controlled heating and material removal of small quantities from the material surface resulting in circular or rectangular shapes. Other shapes can be composed with partly rectangular and partly circular sub-shapes or by making use of other subshapes which include the scanning movement.

The beam is scanning over the material surface in such a way that pulses reaching the surface overlap. The scanspeed, the beamdiameter and the pulse repetition frequency have to be tuned to start up the desired process at a certain powerdensity level.

Figure 2 shows the plume, which is present during the vaporization process. This plume has a very important function. The plume contains material vapour and/or ionised vapour (plasma). The plume absorbs most of the laserenergy. Increasing vaporization of material results in more absorption by the plume. Only a small part of the laserenergy will reach the material surface. The plume therefore is the regulating element in the process, regulating the absorption of laserenergy in the material surface. Due to the successive pulses of energy delivered by the laser the local surface temperature of the workpiece material will increase.
The temperature difference between the actual temperature in the heated spot and the vaporization temperature of the material decreases. At last only a small extra packet of energy is enough to raise the temperature at vaporization temperature to ablate material. By using very low energy pulses at intermediate to high powerdensity levels the material removal can be controlled very accurately.

The length of the plume and its brightness can be used to adjust the process. If the process is working and e.g. more energy is brought into the equilibrium, the surface temperature will rise. As a result more material vapor will reach the plume, increasing its absorption. This effect will reduce the energy reaching the surface and thus the vaporization of material.

As already mentioned the beamdiameter is an important factor. If the beamdiameter increases, powerdensity decreases and the absorption of laserenergy in the material surface decreases.
Selecting a higher powerdensity in the laserbeam the process will work at increased beamdiameter. This effect can be used to regulate the depth of the shape.
The minimum beamdiameter in the focussed beam is adjusted at a position below the workpiece surface then the process is started by adjusting the plume.
Assume the focusplane will remain at a certain level in space. The started process will function as described above until the surface, passing minimum beam diameter, is so far below that the process stops automatically.

For Laser Micro Machining or Micro Milling a pulsed NdYAG-laser can be applied using e.g., pulses of 0.25 ms with 0.05 J. The machining rate depends on the laserfluence (J/cm^2), the powerdensity (W/cm^2) and the applied controlprogram. The controlled local evaporation of surface material is self-adjusting to a pre-defined depth.

A three steps procedure can be applied: pre-machining with a machining rate up to 15 mm^3/min; machining with a machining rate e.g. 0.15 mm^3/min. and post-machining. In this last step practically no material is removed (zero-depth processing). Surface roughness of less than 2 micrometer can be reached. Squared edging is depending on f-number and the depth of the shape. Applications are the making of blind holes and grooves and surface texturing applicable in the manufacturing process and adaption of tools, moulds, stamps and high precision parts for heavy duty.

In figure 3 examples of a processed shapes are shown.

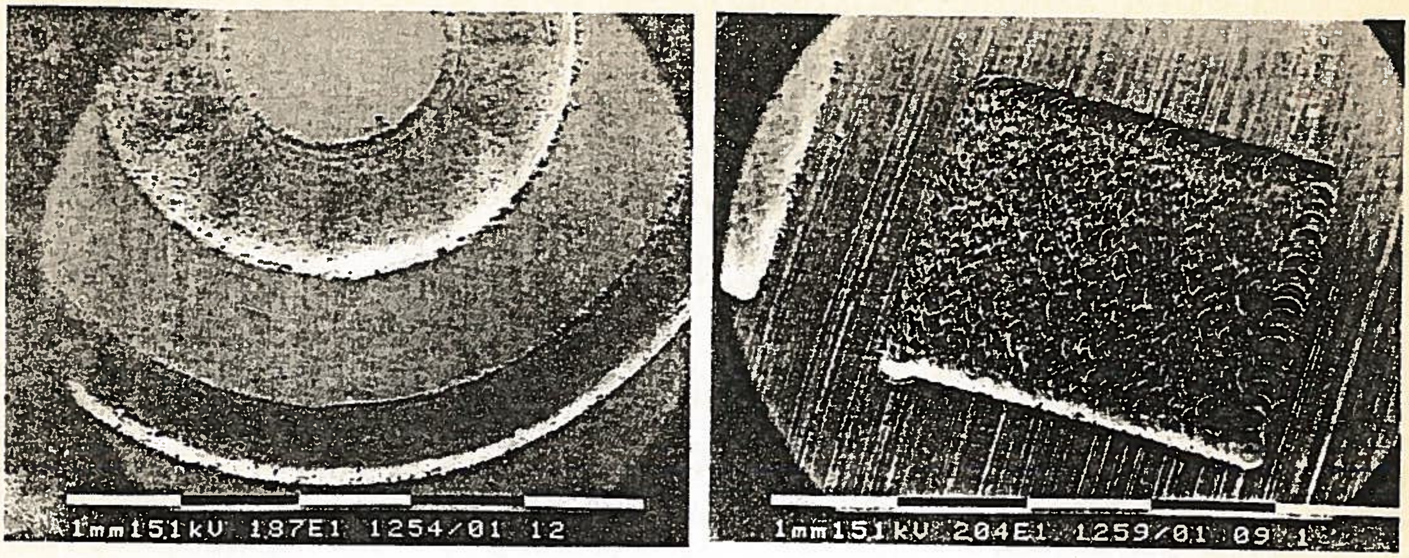


Figure 3 Micro Machined shapes

3. POST-MACHINING

Post-machining is used to finish the machined surface. Several techniques are used, which were developed to finish workpiece surfaces. Surface roughness has been made in the range of 60 micrometers to less than 2 micrometers.

Figure 4A shows an example of a glazy surface which has been made adding N_2-gas during processing. This surface is highly corrosive resistant. Figure 4B shows several visual effects achieved with different post-machining procedures.

Figure 4A Post-machined glazy layer

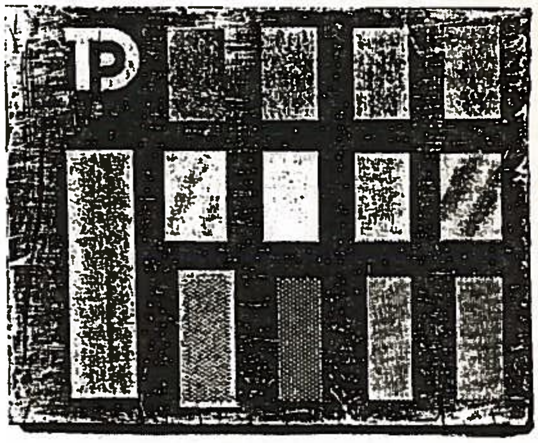
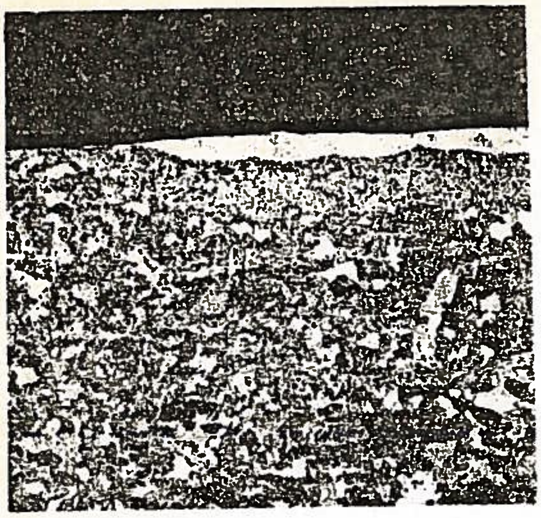


Figure 4B Visual effects on a post-machined surface

When processing hardable steels, a hardened layer is formed automatically, which is of great practical advantage. Figure 5 shows a cross-section of a surface which is only post-machined. This is an example of zero-depth processing. Clearly is shown the hardened layer with a thickness of about 50 micrometers.

Preliminary experiments have been succesfully carried out in the BRITE project "Adaptive Control of Laser Processing". (No. Ri.IB.0129 UK (H)).



Cross-section

Surface

Figure 5 Hardened surface by Micro Machining

** Patent Application pending.