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Micro-machining Processes: Conventional and Hybrid Processes

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The major developments in today's world are made at a submicron level and the biggest challenge today is to be able to fabricate components at increasingly lower dimensions. Our daily routine depend on micro-components and we can find them in the accelerometers of ours car airbag system and mobile phone, for instance. The micro fabrication has its basis in microelectronics and most of research in this field has been focused on microelectronics devices. Nevertheless, the demand for micro-components is increasing in the most various areas like automotive, aviation, electronics, bio-medical, energy and optical fields. It includes systems for microanalysis, micro-volume reactors, microelectromechanical systems (MEMS) and optical components among others. The widening of rage of applications of micro components brings the necessity to machine different materials, many of them difficult to machine, posing challenges to conventional machining processes. For example, the materials that need to be micro-machined can be as diverse as a metallic, ceramic or polymeric: super alloys, titanium, gold, silver, aluminum, copper, chromium, tungsten, nickel, platinum, carbides, silicon, silicon nitride, titanium nitride, etc.

Many machining processes are available and should be selected according to the characteristics of the material that is to be machined. They can work solely as stand-alone (single function) machining tools or they can be combined in groups of two or more processes that are utilized simultaneously (hybrid-micromachining processes).

The Electrical Discharge Machining (EDM) and Electrochemical Machining (ECM) are two non-traditional processes that can be used to produce difficult-to-machine components with components 3D complex shaped features. In the Electrochemical Machining (ECM) the material is removed by the mechanism of anodic dissolution during an electrolysis process where the D.C. voltage is applied across the inter-electrode gap between pre-shaped cathode tool and an anode work piece. The electrolyte should flow at high speed through the inter-electrode gap. The advantage of this process include its applicability regardless the material hardness, no tool wear, comparable high material removal rate, smooth and bright surface, and production of components of complex geometry with stress-free and crack-free surface. This process is capable of machining metals, semiconductors and composites. A combination with other machining processes is also possible in order to enable improved machining characteristics. The combination of ECM with EDM, with Laser or with a vibration tool has been tried as hybrid micro-machining technologies involving ECM.

The Electro Discharge Machining (EDM) is a thermo-electric machining process that shapes the work piece by material removal or erosion. The process relies on a series of electric discharges generated between the tool electrode and the work piece electrode immersed in a dielectric medium. During the sparks, both work and tool are removed by melting and evaporation. The dielectric acts as a deionizing medium between the electrode and work piece, favoring the spark formation and flushing the debris formed in the spark gap. Tungsten, tungsten carbide and copper are the most common tool materials used in micro-EDM. Materials like alumina composites, titanium alloys and magnesium alloys are few examples of materials that have been micro-machined by EDM. Hybrid approaches of EDM such as including vibrations at ultrasonic frequencies and planetary tool movements have shown good results in generating micro-holes with high aspect ratios.

The new trend in micro-machining is replacing the electron based processes by photon systems, and so by Lasers. The reason lies in the fact that in micro-machining with high energy electron beams the penetration of electrons in the surface layers are in depths of many microns and tens of microns, and because the energy is transferred to the atoms in the form of heat over a relatively large zone. This is not suitable for ultra precision machining. On the other hand, the reasons pointed for photons perform better are: their much smaller size relative to electrons, they are electrical neutral which avoids repulsive forces; the optical and thermal penetration depths are only ~10 nm for metals. Short and ultra-short pulse lasers are the most suited for micro-machining operations as they reduce heat affected-damage of the material and enables accuracies in the range of nanometers. Additionally, shorter wavelengths are also sought, as they are better absorbed by the material and allow smaller feature sizes to be produced. The right selection of the type of laser enables the micro-machining of components in almost all types of materials: metals, plastics, ceramics, silicon, inorganic materials, oxides, glass, etc.

The key properties in laser performance are beam quality and output power together with a compact design. The development of diode lasers has successfully fulfilled these requirements relative to conventional CO_2 and lump-pumped lasers. Additionally to these improvements these laser sources provide short (nm) and ultra-short (ps and fs) pulses with very high pulse powers, leading to improvements in process efficiency and opening new fields of application. A short pulse laser with a high beam quality allows the material ablation with high quality. Controlled micromachining and high precision are better achieved by low ablation rates.

The femtosecond lasers are the latest generation of pulsed lasers delivering the shortest pulses, bellow 100 fs. Peak powers of more than 15GW can be reached due to the short pulse duration, resulting in further ablation mechanisms. Due to low optical penetration depth and high heat suppression it allows highest precision and minimum heat influence within the material. Furthermore, this process allows the micromachining of any solid material, although with limitations in the amount of removed material per time. The structuring of medical implants and production of coronary stents of memory shape alloys or stainless steel are examples of applications for femtosecond lasers. Another important application for fs-lasers, exploiting its minimal thermal and mechanical influences, is the cutting of silicon and the high precision structuring of semiconductors, as conventional lasers cause thermal melting, cracks and deposits.

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Another trend that has been seen over the past years is the research on the integration of conventional and non-conventional machining processes, resulting in hybrid micromachining processes that aim to improve the machinability of hard-to-machine materials, multi-material components, tool life, surface integrity, geometrical accuracy and efficiency. Literature classifies them by Assisted Hybrid Micro-machining and Combined Hybrid Micro-machining. In the first case, Assisted Hybrid Micro-machining, the main machining process is superimposed with the input from one or several types of external energy such as ultrasonic vibration, laser, fluid, magnetic field, (etc.). In the second case, Combined Hybrid Micro-machining, each of the involved micro-machining processes simultaneously contributes to the material removal and affects the machining zone. The potential to produce more complex parts with enhanced material removal rate, surface integrity and dimensional accuracy in a relatively short production time is extremely high.

All the above micro-machining presented above are complemented by other processes based on lithography, chemical and plasma etching, printing, molding, transfer and assemble techniques in the production of organic and inorganic micro components of simple or complex 3D shapes.

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