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Fabrication of Micro Channel Using Micro EDM Machine

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ABSTRACT: This paper discusses the fabrication of microfluidic channels using micro end milling and micro electrical discharge (ED) milling on metals and polymers. The width of the microchannels fabricated by micro end milling was 100-800 µm with 1-2 aspect ratio. The average surface roughness values were 100-200 nm and 80-120 nm on metals and polymers respectively. The end milling was found to form more burrs on metallic surface. Micro ED milling, on the other hand, was capable to produce high aspect ratio microchannels on metallic materials without forming any burrs. Using this micro ED milling process, microchannels of 120 µm width and 8-9 aspect ratio were machined with 40-50 nm average surface roughness. Micro swiss-roll combustor mold cavity was machined by using micro ED milling.

I.INTRODUCTION

A microfluidic device has one or more channels with at least one dimension less than 1 mm. The fluid flow through a microfluidic channel is completely laminar as characterized by the Reynolds number in the range of 1-100 (Yager, 2008). A large number of biomedical applications need to manipulate fluids moving through a small channel which is known as microfluidic. This new field stimulated mainly two research areas: (1) development and fabrication of functional microfluidic channels and devices, and (2) fundamental research on microfluidic behaviour in small channels and sophisticated fluid handling capabilities. The use of microfluidic devices has a number of significant advantages. The volume of fluids used in microfluidic channel is very small, usually in the range of submillilitre to several nanolitres. It requires very small amount of reagents which is extremely significant especially for expensive reagents. As a result, the ultimate objective of microfluidic research is to develop lab-on-a-chip (LOC) to integrate laboratory functions in one chip with the handling of very small amount of liquid in the range of nanolitre or picolitres.

It is a sub-set of micro-electro-mechanical systems (MEMS) and often called micro total analysis system (µTAS). It can perform multiple tasks such as mixing, separation, detection, etc. The advantage of LOC includes low cost, high accuracy, less contamination, faster analysis with a very small amount of fluid, etc. (Jung et al., 2007). Micro swiss-roll is also a microfluidic device for energy supply at micro level. It re-circulates fuels through microfluidic channels to generate high density energy within a tiny region (Kim et al, 2007; Ashman and Kandlikar, 2006). Microchannels of thin walls and low thermal conductivity provide higher efficiency of the combustor. It has the potential to substitute lithium-ion batteries widely used in cell phone, laptop, etc. (Ahn et al., 2004; Ronney, 2003). For the development of functional fluidic devices the main concerns are the materials and fabrication processes. Microfluidic devices can be fabricated from a variety of materials such as silicon, metals, ceramics, glass, polymers, etc. However, silicon has been used extensively to create microfluidic devices for the last decades. One of the fundamental requirements of materials for microfluidics is the biocompatibility as most of them are used for biological analysis. The typical fabrication techniques are lithography, wet etching, LIGA(Lithography, Electroforming, and Molding), microreplication, etc. The micro/meso mechanical manufacturing (M4) techniques such as micromilling, micro electrical discharge machining (EDM), etc. are also used to directly fabricate microfluidic channel on metals and plastics (Mateusz et al., 2007). Microfluidic chips were also fabricated using LIGA-similar processes where the metal mold masters were machined with M4 technologies (Ribeiro et al., 2005).

This paper presents and compares two M4 technologies namely micro end milling and micro electrical discharge (ED) milling for the fabrication of microfluidic channels and chips on metals and polymers.

The selection of M4 techniques for the fabrication of microfluidic channel depends on the channel size, aspect ratio, surface roughness, etc. In many cases, it 94 requires initial experiments and investigations before selecting a process for a particular substrate material. In the following sub-sections micro end milling and micro ED milling are discussed for the fabrication of microchannel directly or microchannel master mold for replication in the second stage. Integrated multi process micromachining tool (DT-110: Mikrotools Inc. Singapore) was used for the experiments. This machine integrates several M4 techniques such as micro milling, micro turning, micro EDM, etc. The surface roughness of the fabricated microchannels was measured using a surface profiler (Surftest SV-500, Mitutoyo, Japan and WYKO NT9100, Veeco Instrument Inc., USA). Themachined surface was inspected by scanning electron microscope (SEM) (JSM-5600, JEOL, Japan).

In the last few decades, owing to the rapid developments in micro-electronics and biotechnologies, the applied research in micro-coolers, micro-biochips, micro-reactors, and micro-fuel cells has been expanding at a tremendous pace. Among these micro-fluidic systems, micro channels have been identified to be one of the essential elements to transport fluid within a miniature area. In addition to connecting different chemical chambers, micro channels are also used for reactant delivery, physical particle separation, fluidic control, chemical mixing, and computer chips cooling (Jyh-tong Teng et al, 2012).

Micro channels are primarily used in biomedical devices and micro fluidic applications. Fabrication of micro channels has always been a tough task using conventional manufacturing technologies. Vario-us types of materials are in use for fabricating micro channels in different types of applications including metals, polymers and ceramics. A number of methods are in use for fabricating different types of micro channels. These processes include both conventional and nonconventional fabrication techniques (Prakash Shashi, and Subrata Kumar, 2015). Some of the most established techniques include Micro-machining, lithography, Stereo lithography, Diffusion Bonding Chemical Etching, LIGA, embossing processes, and laser ablation processing, etc. In this paper fabrication of micro channels by electro-discharge machining process using copper sheet as electrode has been reported. Electro-discharge machining or EDM is a machining method primarily used for hard metals or those that would be impossible to machine with traditional techniques.

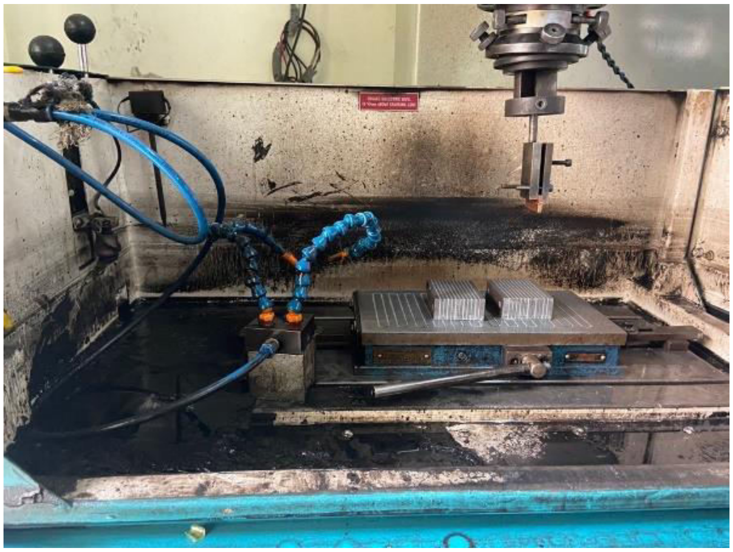

Figure 1: Overview of experimental setup

II.LITERATURE REVIEW

Muneer Khan Mohammed, Usama Umera Abdulrahman Al-Ahmari Optimization of Nd:YAG laser for microchannels fabrication in alumina ceramic (2019) Microchannels are fabricated in alumina ceramic using Nd:YAG direct laser writing . Microchannels having width of 200µm and different depths are machined by varying three parameters viz. intensity of laser beam, pulse overlap and scan strategy

JunZhao, Jin feng Huang, Yong chao Xiang, Rui Wang, Xinqiang Xu, ShimingJi, Wei Hang Effect of a protective coating on the surface integrity of a microchannel produced by micro ultrasonic machining (2021)
In micro-ultrasonic machining (μUSM), slight lateral vibration at the end of the tool inevitably occurs due to tool manufacturing installation errors and mechanical system vibrations. These vibrations cause overcutting and edge breakage, creating undesirable effects on heat transfer and flow deflection. By changing the slurry viscosity and feed rate, the lateral amplitude of the WC tool can be effectively suppressed to improve the over-cutting phenomenon.

Z. Katz · C.J. Tibbles Analysis of micro-scale EDM process (2005). It makes use of dimensionless groups related and relevant to micro electro discharges and their effect on metal removal during the process. The dielectric forms a channelof partially ionized gas.The discharge duration is between 250 ns and 10 μs. The results show that the size of the electrode does have an effect on the discharge process. This is mainly due to the change in the electric field intensity influenced by the electrode sizes at the micro EDM level.

Amit Kumar Singh, Siddhartha Kar and Promod Kumar Patowari Accuracy Improvement and Precision Measurement on Micro-EDM (2020) Tool wear cannot be diminished entirely in μEDM, but measures can be taken to minimize it.
The first and foremost necessity is the selection of processing parameters of μEDM such that tool wear is minimum without impacting machining efficiency and surface quality.

Elumalai Boominathan and S. Gowri in affiliation with Easwari Engineering CollegeChennaiIndia, College of Engineering, AU Chennai India Experimental Study on Micro-deburring of Micro-grooves by Micro-EDM (2019)
This This article describes the experiments conducted to remove top burrs in micro-channels produced by micro-milling. The correlation between burr size and feed rate is studied. The burr formation in the down-milling side always tends to be higher than that on the up-milled side. Moderate feed rate (1.25 μm/tooth) produces better surface quality and less top burrs.
S. N. B. Oliaei Muhammad P. Jahan and Asma Perveen in affiliation with Department of Mechanical Engineering Atilim University, Ankara, Turkey Department of Mechanical and Manufacturing Engineering, Miami University, Oxford, USA Micro-EDM Drilling (2019) This chapter provides a concise overview of the micro-EDM drilling process. It presents working principle of the micro-EDM drilling as well as both operating and performance parameters. Micro-EDM drilling provides comparative advantages over conventional process .This chapter also covers micro-EDM drilling for difficult-to-cut materials such as steel alloys, Ti alloys and Ni alloys.

III.METHODOLOGY

The microfluidic channels produced on metallic and plastic materials using micro end milling and micro ED milling were investigated based on width, depth (aspect ratio = depth ÷ width), burrs, and surface roughness. Microchannels on metallic materials were fabricated using both of the milling techniques. It was found that higher aspect ratio and surface finish could be achieved on plastic substrate compared to metallic one. Moreover, formation of burr was a critical issue in micro end milling which requires a deburring process. The micro end milling was more prone to form burr on metallic substrate.

Alternatively, micro ED milling is a burr free process for fabricating microchannels on conductive metallic materials. This process is not applicable for machining of polymeric materials. However, it is usually used for fabricating master micro mold cavity for the replication of microchannels on polymer and ceramic substrates.
The size of the structures produced by micro end milling are in the range of 500-800 μm, where as micro ED milling has been applied to produce microchannels as small as 100 μm with very high aspect ratio of more than 8 (Fig. 5b). Very high surface finish (40 nm R_a) was achieved on the mold cavity which will result easy demolding and high surface finish on replicated polymer microfluidic channels. Higher aspect ratio and few tens of nano meter surface roughness are difficult to achieve by micro end milling. For the machining of micro swiss-roll mold cavity, layer by layer material removal approach was used to produce deeper channel with high dimensional accuracy. The thickness of each layer was 100-200 μm. The gap between two microchannels (i.e., wall thickness) was 380 μm. After machining each 500 μm, the tool-electrode was dressed by micro WEDG to achieve higher shape and dimensional accuracy.

Micro-fluidic channels of different channel width, channel depth and having varying surface roughness are fabricated by varying the input parameters such as peak current (I), spark time (S) and pulse-on time (P). These input parameters were kept low in order to have a good surface finish and lesser channel width. The peak current was varied from 2 to 10 A, the spark time from 1 to 5 µs and pulse-on time from 18 to 28 µs. The low pulse-on time facilitates proper flushing of the eroded debris. Each of the above parameters was varied in discrete steps. I represents current in Ampere, P is pulse-on time (µS), S denotes spark time (µS), C_w represents channel width (µm), C_d denotes channel depth (µm) and R_a is surface roughness of channel (µm).

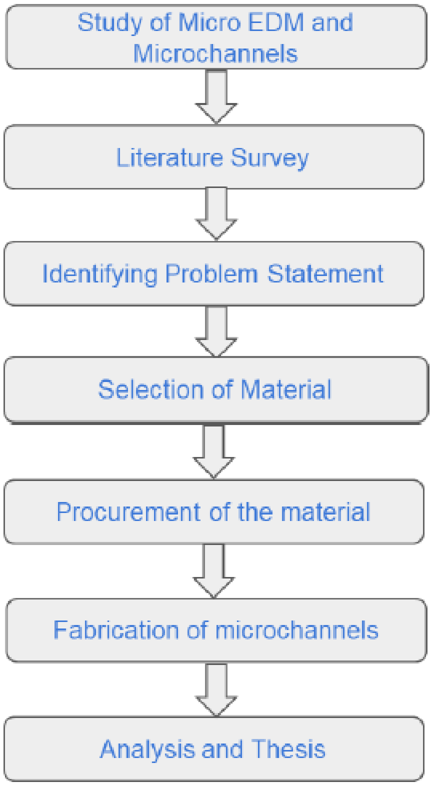

Figure 2 : The below methodology was followed along the course of the project.

A total of 20 experiments with different input parameters keeping a constant duration of 150 s were conducted. The channel width, channel depth and channel surface roughness were measured using the non-contact surface profilometer and optical microscope. The input parameters and corresponding responses are illustrated in illustrates the fabricated micro-fluidic channels and shows the fabrication of micro-channels. From the experiment conducted, it was found that at 8 A peak current, 20 µs pulse-on time and 2.0 µs spark time, the average value of channel surface roughness (R_a) was found to be the lowest among others (2.9 µm). For the same parameter, the channel width and depth were 170 and 38.2 µm, respectively.

These values of input parameters were then selected for the fabrication of a Yshaped micro-fluidic system. At the starting point of micro-channels, a micro-hole is also fabricated. Micro-holes at the outer end of each micro-channel are used to deliver the fluid into the channel. Two different fluids are delivered from each of the two limbs of the Y-shape channel system and the mixture was collected through the third outlet limb. This system is used as a prototype to show a typical application of micro-fluidic channels fabricated through die sinking EDM. After the fabrication of this Y-shaped channel, the feasibility of this channel for the efficient mixing of the fluids were analysed. Two different coloured fluids were injected using syringes through two upper limbs. The necessary turbulence needed for the efficient and proper mixing of these fluids was provided by the surface roughness of the channel. This roughness has to be optimized depending upon the nature of fluids to be mixed, for example, specific gravity and miscibility.

IV.RESULTS

The width and depth of micro-fluid channel were measured using a Zeiss optical microscope at 5× magnification and non-contact surface profilometer. Figure shows the channel from the inputs (Table 2). The last channel corresponds to I = 2 A, P = 1 µs and voltage =230v when compared to the 8th channel which was fabricated with higher pulse on time which recorded the higher Ra value, which shows that surface roughness increases as the pulse-on time is increased. It is also observed that the channel width and depth increased with an increase in the value of pulse-on time.

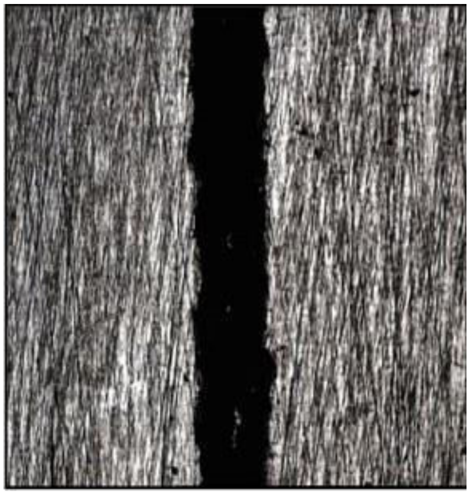

Figure 3 : Results of micro fluid Channel

V.CONCLUSION AND FUTURE WORK

This paper describes and compares the fabrication of microfluidic channel using micro end milling and micro ED milling which are extensively used in micro/meso scale fabrication. Microchannels on metals and polymers were fabricated. Micro swiss-roll mold cavity of aspect ratio 8 was fabricated using micro ED milling. The following conclusions can be made from this experimental research.

1. Although, micro end milling can be used for metals and non-metals, it forms more burrs on metallic channels compared to that of plastic microchannels. As a result micro end milling is recommended for direct fabrication of microchannels on polymeric materials.
2. The micro ED milling process is not directly applicable for machining microchannels on polymeric materials. However, this process is used to fabricate master mold to replicate microfluidic channels on polymer by micro hot embossing which is a cheaper and reproducible mass production technique.
3. It is possible to produce high aspect ratio (8-10) microchannel using micro ED milling, whereas only 1-3 aspect ratio can be achieved by micro end milling. The surface roughness produced by micro ED milling (40-50 nm R_a) is much lower than that of micro end milling (100-200 nm R_a). Micro ED milling produces no burr.

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