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Comparison of Micro-Holes Produced By Micro-EDM with Laser Machining

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Abstract—In the MEMS and micro machining worlds, micro-hole making is among the most frequently performed operations. There are many machining processes such as electro-discharge machining (EDM), laser beam machining (LBM), electro-chemical machining (ECM) and ultrasonic machining (USM) etc., used for creating micro-holes. But each machining process has its advantages and disadvantages depending upon the hole diameter, aspect ratio and material used. In this research paper, micro-holes were produced using the laser machining process and these micro-holes were compared with micro-holes produced by micro-EDM. The comparison is done for MRR, dimensional accuracy (including diameter at the entrance and exit, overcut, taper angle and circularity) and surface topography of micro-holes.

Index Terms—micro-holes, micro-EDM, LBM.

I. INTRODUCTION

Modern manufacturing systems, mostly concentrates on micro manufacturing. Where maximum effort goes towards reducing product sizes to micron sizes to save space, material and money. Therefore, the requirements for the use of advanced engineering materials, precise and complex design and micro-size products have restricted the use of conventional machining processes. Hence, the demand for the use of unconventional machining processes (such as electro-discharge machining, laser-beam machining, electron-beam machining, ion-beam machining, plasma-beam machining, electro-chemical machining, chemical-machining processes, ultrasonic machining and jet-machining processes, which are also known as advanced machining processes) have increased drastically. But all the processes have their own advantages and limitations based on the type of material and machining conditions. However, micro-holes machining is mostly realized by using micro-EDM and laser machining processes.

EDM is a spark erosion process, in which material is removed by means of an electric spark generated between conductive materials (i.e., tool electrode and workpiece material) by means of an electric generator, immersed in a dielectric medium. In micro-EDM, the energy generated is at the micron level. Micro-Electro-discharge machining is used for machining micro features in various kinds of advanced engineering materials which are electrically conductive [1].

Micro-EDM is one of the most efficient methodologies to produce simple and complex shapes, cavities, 3D micro-profiles. Several studies have been reported for micro-EDM machining. Masuzawa et al. using micro-EDM successfully fabricated micro-pins, micro-nozzles and micro-cavities, 3D shapes and fabricated nickel micro-pipes using WEDM and electro-forming process [2-3]. Yan et al. Describes the characteristics of micro-hole of carbide produced by micro-EDM using copper tool electrode and investigated the effects of various machining parameters on the quality of micro-holes [4]. M.P. Jahan et al. studied the quality of micro holes produced by micro-EDM and investigated the influence of parameters on performance of micro-EDM of WC in obtaining high quality micro-holes, good surface finish and circularity [5]. M.S. Rasheed et al. analyzed the effect of micro-EDM parameters on MRR, TWR and Ra while machining Ni-Ti SMA (shape memory alloy) and it was observed that the MRR, TWR and Ra depends upon the discharge voltage, capacitance and thermal properties of the electrode and workpiece materials [6].

Laser beam machining is one of the widely used advanced machining processes. Laser machining is a localized, non-contact machining and almost reaction-force free thermal process, used for machining all kinds of advanced engineering materials (metallic and non-metallic). During the material removal process, the laser beam is focused on the workpiece material surface, where melting, vaporization and chemical degradation take place, followed by high pressure assisted gas jet which clears the machining zone. The most widely used laser is Nd: YAG and CO_2. Laser beam machining is commonly used for cutting, marking, engraving and making holes. The laser machining process is frequently used in various industries such as aerospace, automotive, bio-medical and MEMS etc [7-8]. Nd: YAG laser and Excimer pulsed laser are widely used in the micro-machining applications, medical and electronic industries [9]. Laser beam drilling is also used for drilling closed spaced economical holes. Voisey et al. used Nd: YAG laser drilling at various densities of power and studied the melt ejection phenomenon in different metals, observed that MRR increases with an increase in power density [10]. B.T. Rao et al. studied the effect of high power CO_2 laser for machining concretes and observed that the MRR dramatically increases with an increase in laser power and scanning speed [11]. Pham et al. Reported Laser milling is used to manufacture micro-parts of difficult-to-machine materials by using layer by layer material removal technique through chemical degradation [12]. Shanjin et al. reported the cutting of Ni-Ti SMA uses laser radiation [13]. Lie et al. used hybrid machining processes with EDM and LBM successively in drilling micro-holes of fuel injection nozzles and reported that quality of micro-holes increased with better MRR [14].

In this paper a comparative study is done between micro-EDM and laser machining processes based on MRR, overcut, taperangle, circularity and the surface topography of the micro-holes.

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Experimental procedure

In this research paper, a sheet of Ni-Ti shape memory alloy (SMA) of 100 µm thickness is used as the workpiece, the material properties are shown in table 1.

Table 1: Workpiece material properties

Workpiece materials	Ni-Ti SMA
Composition	Ni: 55.8%, Ti: 44.2%, C<0.02%
Density (kg/m^3)	6500
Melting point (◦C)	1310
Electrical resistivity (µΩ-m)	820
Modulus of elasticity (MPa)	41-75x10 3
Total Elongation (%)	10

A. Micro-EDM Set-up

The experimental setup shown in fig. 1 has been used to study the micro-EDM process consisting of an RC type generator. This generator can produce pulses from few tens of nanoseconds to a few micro-seconds. The power supply can vary voltage levels from 45V to 120 V. An Optical microscope is used to investigate the micro-holes formed by micro-EDM set up.

Fig.1: micro-EDM Set-up (T. Masuzawa)

Fig. 2 shows a schematic diagram of micro-EDM. The electrode materials used are tungsten and brass electrodes (diameter-100µm).

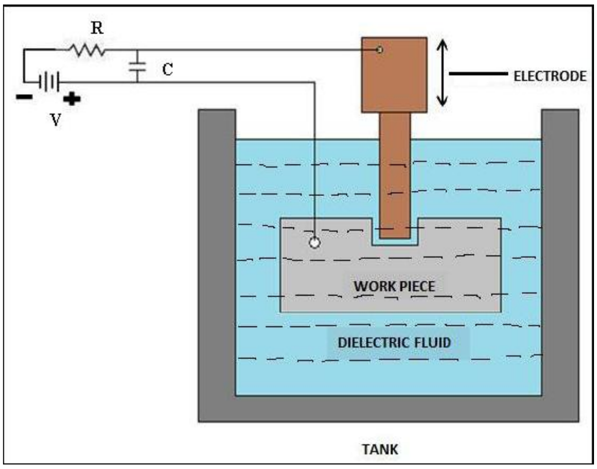


Fig. 2: Schematic diagram of micro-EDM

B. Laser machine Set-up

Lasertech 40 from DMG with Flashlamp pumped Q-switched Nd: YAG laser was used for drilling micro holes in SMA. Fig. 3 shows the laser machine. The basic parameters of the laser are tabulated in table 2. Schematic diagram of the laser system is shown in fig. 4.

Fig. 3: Laser Machine from DMG

In this study for producing micro-holes using LBM, a number of experiments were performed and appropriate parameters which give best micro-holes in shape and size were selected for comparison.

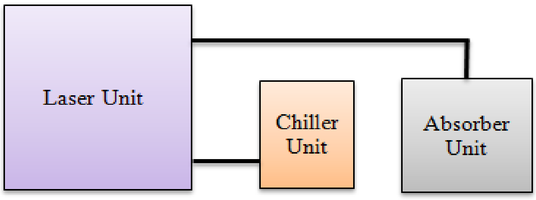


Fig. 4: Schematic diagram of laser machine

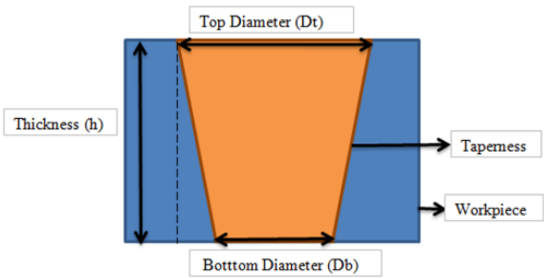
Table 2: Laser parameters

Wavelength	1064nm
Pulse duration	10 us
Frequency	35 KHz
Laser spot diameter	30 um
Scanning speed	300 /sec

The Laser beam is focused onto the workpiece after setting up the parameters. Holes of 100 µm diameter were machined and machining time was noted. The machined holes were analyzed through SEM to find the hole diameter, taperness and heat affected zone (HAZ).

C. Performance Measurements

The performance of micro-EDM and laser machining processes were evaluated by calculating MRR, accuracy of micro-holes i.e., overcut, taper angle and circularity of micro-holes produced as shown in fig. 5.



(a)

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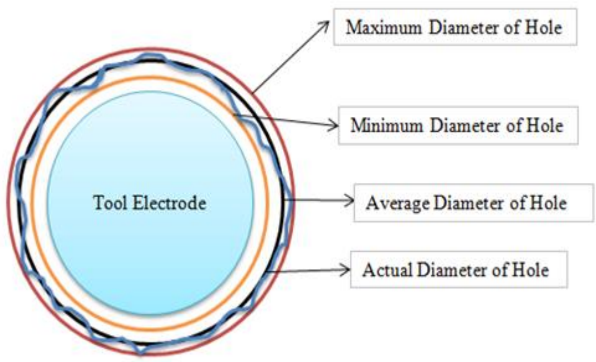

(b)

Fig.5: (a) Measuring taperness (b) Overcut and circularity of micro-holes

Material Removal Rate (MRR)

In micro-EDM and laser machining processes, the MRR is calculated as the average volume of the material removed to the machining time and generally expressed in cubic millimeter per minute. General Volume formula considered for MRR in workpiece is the volume of a conical frustum which is given below.

$$MRR = \{\prod/3\ [R^2_t + R^2_t R^2_b + R^2_b]\ x\ h\} \div t$$

Where R_t is the radius at the entrance of the micro-hole produced.

R_b is the radius at the bottom of the micro-hole produced.

h is the thickness of workpiece material.

t is the machining time to make a micro-hole.

Overcut

The overcut of micro-hole is one of the accuracy aspects of micro-holes, which is evaluated by calculating the difference between the average diameter of micro-hole after machining and the diameter of tool electrode. The formula is given as

$$Overcut = \{(D_a - D)/2\}$$

Where D_a is the average diameter of micro-hole produced.

$$D_a = \{(D_t + D_b)/2\}$$

Where D_t is the Top diameter of micro-hole produced.

D_b is the Bottom diameter of micro-hole produced.

D is the tool diameter.

Taper angle

Taperness is measured as the difference between the entrance diameter and the exit diameter of micro-hole and the angle between them is known as taper angle and it is given as

$$Taper\ angle\ (\alpha) = \tan^{-1}\{(D_t - D_b)/2p\}$$

Where α is the taper angle

II. RESULTS AND DISCUSSIONS

A. Comparison of MRR between micro-EDM and LBM

In this experimental study, a comparison of material removal rate is made between micro-EDM and laser machining processes. In micro-EDM, it was observed that the MRR increases with an increase in discharge energy and it was also observed that the MRR also depends upon the thermal and physical properties of the electrode and workpiece material. Faster machining rate is observed with brass electrode than that of tungsten electrode for machining Ni-Ti SMA.

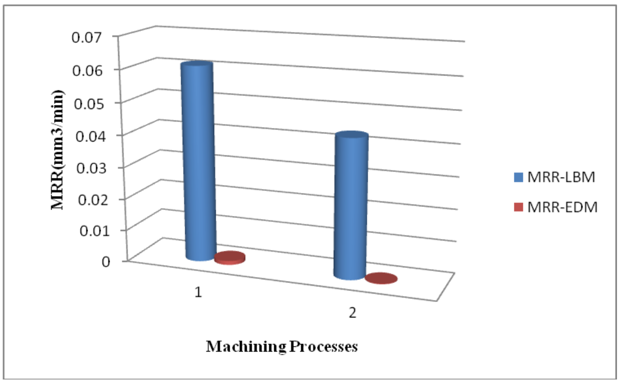

Fig. 6 Comparison of MRR of micro-hole obtained by LBM and micro-EDM

The material removal mechanism in LBM involves a combination of melting and evaporation process. In this process, most of the energy is utilized for melting the material and a part of it is used to evaporate the material. In LBM faster solidification of molten material takes place which forms the recast layer. The solidification process of recast layer is the same as that of the fusion welding process but they differ in the amount of liquid metal which is in few hundred microns thick. The cooling rate of recast layer is very fast because the rest of the parent material acts as a heat sink. In laser machining process, MRR depends upon the wavelength, pulse duration, scanning speed and frequency. It was observed that with an increase in intensity of wavelength and frequency the MRR increases but affects the dimensional accuracy.

In this section, the MRR obtained by LBM is compared with MRR of micro-EDM as shown in fig. 6. It was observed that MRR is much higher in LBM process compared to micro-EDM. The maximum MRR was observed to be 0.06 (mm^3/min) in the laser machining process and under 0.01 (mm^3/min) for micro-EDM. Therefore, it was observed that micro-EDM is a slow process compared to the laser machining process.

B. Comparison of dimensional accuracy between micro-EDM and LBM

In any machining processes, the main area to be considered after machining is its dimensional accuracy which determines the quality of the product. Therefore, in this research paper the dimensional accuracy is evaluated based on micro-holes entrance and exit diameter, overcut, taper angle and circularity of the micro-holes produced.

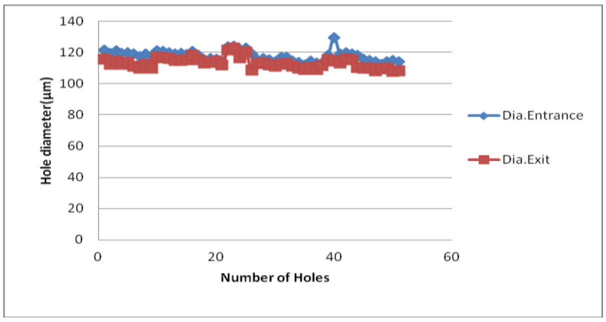

Fig. 7 comparisons of micro-holes diameter of entrance and exit for micro-EDM

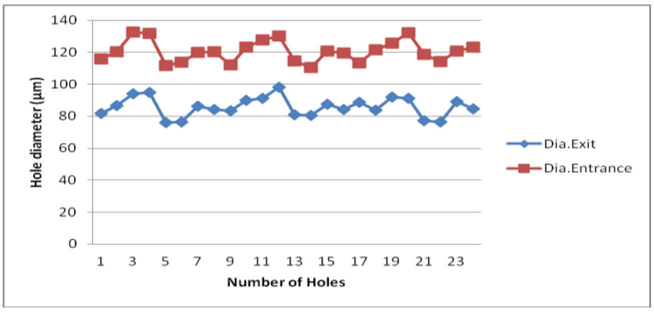

Fig. 8 comparisons of micro-holes diameter of entrance and exit for LBM

From fig. 7, it can be observed that the diameter difference between the entrance and exit of micro-holes produced by micro-EDM is much less as compared to micro-holes produced by LBM. On average the diameter at the entrance of micro-hole is about 118µm and the minimum diameter of the exit is 112 µm for micro-EDM. Whereas in case of LBM on average the diameter of micro-hole at entrance is 120.64 µm and the average diameter of the exit of the micro-hole is 85.84 µm as shown in fig. 8.

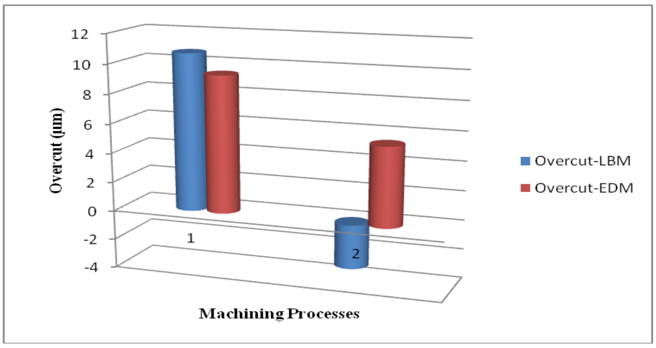

Fig. 9 Comparison of overcut of micro-hole obtained by LBM and micro-EDM

In micro-EDM, the overcut increases with an increase in discharge energy and it was found to be more at higher discharge energy levels. The one reason for overcut is improper flushing of the dielectric fluid which results in expansions at the micro-hole entrance diameter. The other reason for overcut is due to the debris formed around the periphery of the micro-holes, which cause secondary sparking and results in a larger entrance diameter.

From fig. 9, it was observed that the overcut in the case of micro-hole produced by LBM is more due to increased laser power and it was also sometimes observed that there is a negative overcut because of the convergence/divergence of the laser beam. Which is also a reason for the increase in taper angle other than pluse frequency.

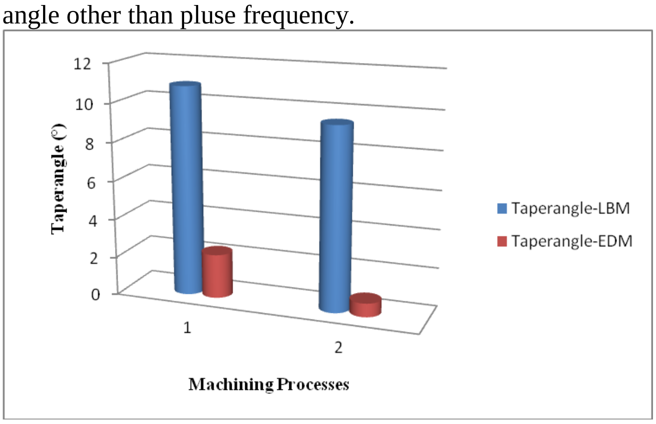

Fig. 10 Comparison of taper angle of micro-hole obtained by LBM and micro-EDM

From fig. 10, it was observed that the taper angle in case of LBM machined micro-holes are more than the taper angle in micro-holes produced by micro-EDM. And from fig.11, it can be seen that the circularity of micro-holes is higher in the case of micro-holes manufactured by micro-EDM and with LBM process the poor circularity of micro-holes are observed. It's also observed that the taper angle and overcut also depends upon the thickness of the material.

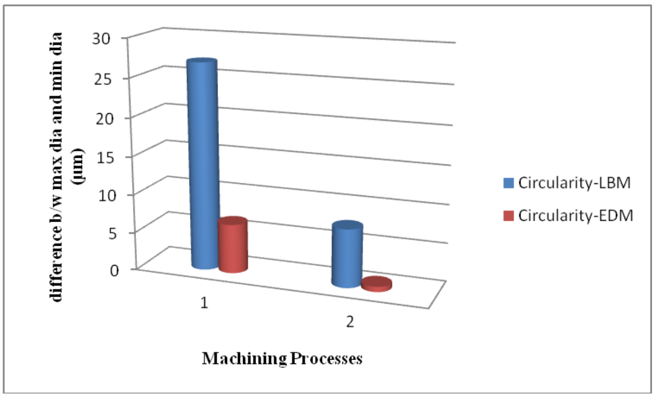

Fig. 11 Comparison of circularity of micro-hole obtained by LBM and micro-EDM

C. Comparison of Surface topography between micro-EDM and LBM

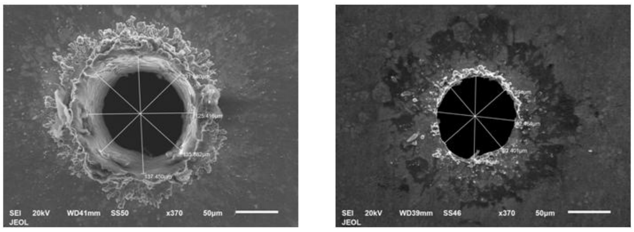

Fig. 12 SEM images of micro-holes at the entrance and exit sides obtained by LBM

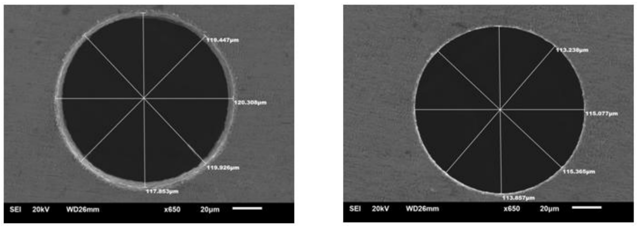

Fig. 13 SEM images of micro-holes at the entrance and exit sides obtained by micro-EDM

The other parameter which represents the quality of the machined surface is the surface topography. In this section, the quality of the micro-hole is evaluated based on the SEM images. Laser machined micro-holes were associated with high degrees of taper, low circularity, heat affected zone (HAZ), recast layer and spatter around the periphery of the holes as shown in fig. 12. However, the material removal rates were very high. The taper in laser-drilled holes is caused by the expulsion of molten and vaporized material from the hole. The high degree of taperness is also because of the collision of the laser beam with the walls of the hole resulting in the excessive cut at the top surface.

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A thin layer formed from the re-solidified molten material on the side walls of the cavity is termed as recast layer. Spatter is the re-solidified and adhered molten metal and vapor at the periphery of the hole. Spatter cannot be completely eliminated but can be reduced by proper selection of process parameters. The use of a shorter pulse width and optimized parameter setting helps reduce the spatter area deposition and less HAZ. It was observed that the spatter around the micro-hole and HAZ is less in the case of micro-hole produced by micro-EDM as shown in fig. 13. And the quality of micro-holes obtained by micro-EDM is much better with less spatter around the periphery of the holes. It was also observed that the surface quality of the micro-holes produced by LBM can be increased significantly by increasing the cutting speed and frequency and decreasing the laser power.

III. CONCLUSION

From the above discussion it can be concluded that the performance of micro-EDM and LBM mainly depends upon the machining parameter. In micro-EDM, MRR and dimensional accuracy is mainly depends upon the discharge energy and thermal properties of the material. Where as in LBM, it mainly depends upon the machining parameters such as laser power, wavelength, pulse duration and frequency. MRR is much higher in case of LBM but lacks in surface quality and dimensional accuracy as compared to the micro-holes produced by the micro-EDM. The HAZ around the micro-hole machined by LBM is higher as compared to the micro-hole machined by the micro-EDM. Therefore, it can be concluded that LBM can be used for higher MRR when surface quality is not a criterion. Finally, the positive features of micro-EDM and LBM process can be utilized to make it a hybrid process, which increases the MRR with good surface quality.

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