CHAPTER 1
INTRODUCTION

In recent years, rapid advances in manufacturing industries have given rise to miniature and lightweight products with increasing and more powerful functions. With the increasing demand for micro parts and structures in many industries, and rapid developments in micro-electro-mechanical systems (MEMS), micro-manufacturing techniques for producing these parts has become increasingly important. The machining of difficult-to-machine materials is an important issue in the field of manufacturing. Since these materials possess excellent mechanical properties which can be useful in many important applications, machining of them can open up opportunities of utilizing them comprehensively. In order to overcome the technical difficulties in conventional machining and the high costs associated with the elevated hardness and intrinsic brittleness, non-conventional machining has been developed.

1.1 ELECTRICAL DISCHARGE MACHINING - FEATURES

The non-conventional material removal processes are widely used in machining micro-structures. Currently, micro-holes are formed by different manufacturing methods, including electrical discharge machining (EDM), micro-electrical discharge machining (micro-EDM), electron beam machining (EBM), laser machining, etching, electro-chemical machining (ECM), micro-ultrasonic machining (MUSM), micro-mechanical drilling, micro-punching (Diver et al. 2004, Her and Weng 2001, Kaminski and Capuano 2003, Kim et

EDM is one of the most promising manufacturing technologies of micro-components. One of the major advantages of EDM over the conventional machining process is that it is an electro-thermal process of removing metal regardless of hardness where the force between the workpiece and tool is insignificant. Thus, the error caused by the tool deformation due to force is almost zero (Tsai and Masuzawa 2004). There is no chatter, mechanical stress or vibration problem during the machining as there is no direct contact between the electrode and the workpiece (Ho and Newman 2003). Therefore, EDM has been considered as one of the most effective methods of machining hard conductive materials.

EDM is a technique in which machining of conductive materials is implemented by sequential electric discharge pulses generated between tool electrodes and the workpiece. It evaporates and melts the material of the workpiece by the high temperature of the electrical discharge, and removes debris by the explosion pressure of the electrical discharge, enabling the manufacture of components. Generally, the tiny size of the manufactured micro-component will increase the difficulty of manufacturing, but EDM uses high temperatures generated from electric sparks to remove the processed material. Hence, the processed material is not easily deformed by EDM, and it is suitable to machine all kinds of super-hard alloys (Reynaerts et al. 1998, Yammamoto et al. 2000).

1.2 MICRO-EDM

Micro-EDM is the application of EDM in micro-field. It has similar characteristics as EDM except the size of the tool, discharge energy and axis movement resolutions are in micro-level (Masuzawa 2000).
The basic principle of micro-EDM is the same as that of the EDM process. In EDM, a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be electrically conductive, submerged in dielectric fluid. Generally, kerosene or deionized water is used as the dielectric medium. The micro-EDM system has a servo system with very high sensitivity and positional accuracy of ±0.5 μm (Shober 1983). Due to such precision it is possible to maintain a minimum gap of 1 μm between tool and workpiece. Depending upon the applied voltage and the gap between the tool and workpiece, an electric field would be established. The voltage applied to them must be enough to create an electric field higher than the dielectric strength of the fluid used in the process.

During the machining process, the electric field maintained between the tool and workpiece electrodes creates a plasma channel in the dielectric, facilitating electrons flow and consequent sparking of the work material. The electrical resistance of the plasma channel allows an avalanche of electrons. Such movement of electrons along with the movement of the tool electrode facilitates controlled sparking. The intensity of the spark regulated by the machining conditions would cause instantaneous erosion of the work material (due to localised vapourisation). The shape of the machined feature depends on the shape and size of the tool electrode. Electro discharge (spark) machining can be used for roughing/precision operation depending on the current intensity. Thus, micro-electro discharge machining is carried out with milli/micro ampere current rating.

Although micro electro-discharge machining is considered a relatively new technology, the groundwork for micro-EDM was laid in 1968 by Kurafuji and Masuzawa (1968). They were able to produce a 6μm hole in a carbide block 50μm thick with the process. The technology grew rapidly and
was introduced into production by Matsushita Electric Industrial Co., Ltd. through the research of Masuzawa and colleagues (Allen 2002).

Most of the machining parameters are determined based on experience or handbook values some time. This does not ensure the optimal or near optimal performance. To solve this task, various approaches are used to determine the optimal machining parameters in the EDM and micro-EDM processes. Taguchi based grey relational analysis is one of the most promising optimization techniques to solve the multi-response optimization problems.

Genichi Taguchi, a Japanese scientist, developed a technique based on orthogonal array (OA) of experiments. This technique has been widely used in different fields of engineering to optimize the process parameters. The integration of design of experiments (DOE) with parametric optimization of process can be achieved in the Taguchi method. An OA provides a set of well-balanced experiments, and Taguchi’s signal-to-noise (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a small number (minimum experimental runs) of experiments.

OA and S/N ratios are used to study the effects of control and noise factors and to determine the best quality characteristics for particular applications. The optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. However, originally, the Taguchi method was designed to optimize single-performance characteristics. Optimization of multiple performance characteristics is not straightforward and much more complicated than that of single-performance characteristics. To solve the multiple performance characteristics problems, the Taguchi method is coupled with grey relational analysis (GRA). GRA was first proposed by Deng (1982) to fulfill the crucial mathematical criteria for dealing with poor,
incomplete, and uncertain system. This grey-based Taguchi technique has been widely used in different fields of engineering to solve multi-response optimization problems.

1.3 ADVANTAGES OF MICRO- EDM

The use of micro-EDM has many advantages in micro parts and the main advantages are manufacturing micro-components with excellent dimension precision, shape precision, good surface finish and a large batch of production. It can machine complex shapes into any conductive material with very low forces. As a low cost non-traditional machining technology, it has special advantages in machining complex micro-structures (Muttamara et al. 2003).

The mechanical forces are very small because the tool and the work material do not come into contact during the machining process (Ekmekci et al. 2009). Very small process forces involved and good repeatability and reliability of the process have made micro-EDM the most sought-after technique in micro-machining for achieving high-aspect-ratio micro-parts/holes. The growing popularity of micro-EDM can also be attributed to its advantages, including low set-up cost, high aspect ratio of parts, enhanced precision and large design freedom (Lim et al. 2003).

Moreover, micro-EDM also provides the advantages of being able to manufacture components with various 3D shapes and machine the materials whose dimensions are only tens of microns and weight is generally very low.

Furthermore, micro-EDM can be combined with other manufacturing technologies to manufacture the micro components. Further, it
can be used to manufacture insulators such as glass, by combining it with electro-chemical machining (ECM) (Yang et al. 2001).

### 1.4 APPLICATIONS OF MICRO-EDM

Parts produced by micro-EDM are widely used in MEMS, biomedical applications, automotive industry, and defence industry. There have been several successful attempts in producing micro parts such as micro pins, micro nozzles and micro cavities using micro-EDM.

The main goal of micro-EDM is to achieve a better stability and higher productivity of the micro-holes. Machining capability of micro-EDM using conductive materials with high precision regardless of material hardness, creates a wide range of application area with the increasing demand for miniaturized parts and components such as holes, gears and micro cavities. It is also used to make gasoline injector spray nozzles, dies for extrusion, liquids and gas micro fields, needles for the medical field and in semi conductor industries to produce electrolysis needles (spiral electrodes). Micro-EDM has also made its presence felt in the new fields such as MEMS, medical and surgical instruments. It has also become popular with its potential applications in pharmaceutical industry, orifices for biomedical devices, micro-fluidic channels, cooling vents for gas turbine, turbine blades of jet engines, military affairs, aerospace industries and automobile industries, heat exchangers, micro-gears, micro-robot, micro-robotic arm and micro-stage.

### 1.5 SIGNIFICANCE OF THE RESEARCH

Micro-EDM has many advantages and unique applications. Many research works have been carried out to solve a number of issues to produce good quality micro components.
The quality and integrity of surface of die-sinking micro-EDM have a significant impact on the product performance. Surface wear, surface crack, craters, residual stress and the formation of recast layer with ragged surface strongly affect the micro mechanism for reducing the fatigue strength. Many research works have been carried out with an anticipation of achieving fine surface finish in the products fabricated by the micro-EDM.

In die-sinking micro-EDM, an electrode with micro features is employed to cut its mirror image in the workpiece. Hence, the selection of electrode is of prime importance in the die-sinking micro-EDM. Furthermore, in order to increase the machining efficiency, the erosion of the workpiece must be maximized with the minimum tool wear. Electrode wear also imposes high cost on manufacturers to substitute the eroded complicated electrode by new ones for die-making. Mostly the tool electrode material is subjected to relatively severe working environment demanding proper selection of the material. Thus, the influence of different electrodes (materials) and related factors on machining productivity and process reliability is to be clearly understood for effective application in the production of miniature features and precision components.

Therefore, it is observed that even though micro-EDM is an extensively used manufacturing process, due to its cost effectiveness and capability to machine any conductive materials irrespective of its hardness, it cannot satisfy all the requirements of the product performance. There is a need to investigate the performance of various electrodes which play a significant role in die-sinking process. In this regard, this study analyzes the performance of die-sinking micro-EDM of EN24 die steel using different electrodes such as tungsten (W), copper (Cu), copper tungsten (CuW) and silver tungsten (AgW) in order to make it a more feasible process. EN24 die steel has high dimensional stability with added wear resistance coupled with
excellent edge holding qualities. It is readily machineable and combines a
good high tensile steel strength with shock resistance, ductility and wear
resistance. Originally EN24 was introduced for use in the motor vehicle and
machine tool industries but later its applications became much more extended.
It is also suitable to produce parts for locomotives, cranes, rolling mills, coal
cutting machinery where good strength and fatigue resistance is called for.
The major applications of EN24 include aircraft and heavy vehicle crank
shafts, connecting rods, micro manufacturing industries, pressure casting
moulds and cold extrusion tools and dies.

The main implication of this research is to identify the electrode
which enhances the production of quality micro-holes and to significantly
contribute to modern industries.

1.6 OBJECTIVES OF THE RESEARCH

The main aim of the present study is to understand and enhance the
performance of die-sinking micro-EDM. The objectives are as follows:

- To study the die-sinking micro-EDM of EN24 die steel using
different electrodes,
- To evaluate the influence of machining conditions on the
performance of micro-EDM process and arrive at the apt
condition for desired results (Preliminary trials),
- To investigate experimentally the feasibility of achieving
higher material removal rate (MRR), lower tool wear ratio
(TWR), fine surface finish and to obtain quality micro-holes,
To examine the effect of different operating parameters such as gap voltage, capacitance, feed rate and threshold on the performance characteristics,

To evaluate and compare the performance of different electrodes in producing micro-holes in die-sinking micro-EDM,

To arrive at the optimal parameters to obtain higher MRR, lower TWR and minimum surface roughness using Taguchi-based grey relational analysis, and

To model the micro-EDM process relating the machining performance with machining conditions statistically using multi-regression techniques.

1.7 ORGANIZATION OF THE THESIS

This thesis consists of five chapters.

Chapter one gives a brief introduction to the demand of miniaturisation and the necessity of non-conventional machining processes. It discusses the significance of EDM, Micro-EDM processes, its principle and applications. It also highlights the scope and the objective of the present research.

Chapter two provides a comprehensive literature review, which includes various researches on input parameters such as influence of dielectric fluids, pulse characteristics and induced ultrasonic vibration of the electrode on machining performance in terms of material removal rate, tool wear ratio and surface integrity. It also highlights the output parameters like material removal rate, tool wear ratio, surface roughness, circularity error, overcut,
micro-cracks and heat affected zone. It focuses on various optimization techniques such as Taguchi method, Grey relational analysis and Artificial Neural Network (ANN) on performance. Some of the research work in the micro-EDM process based on mathematical modeling also been highlighted. At the end of this chapter, the research opportunities and problems are identified and the need for the present study is established.

Chapter three describes the experimental details. This is done in three parts. In the first part, details of the experimental set-up are given. It also illustrates the details of the experiments done in micro-EDM, i.e., selection of tool and workpiece materials, the specifications of the dielectric used and the details of experiments using different electrodes. The second part illustrates the experimental procedure used in this study. It gives a brief description of preparation of the workpiece, a summary of the different machining parameter settings and machining details used throughout the experiments. The third part gives brief descriptions of the different measuring equipments used.

Chapter four presents the results obtained from the experiments done with different electrodes and studied the overall machining performance of die-sinking micro-EDM in terms of material removal rate, tool wear and surface roughness. The detailed analysis of overcut, circularity error, heat affected zone, micro-cracks and migration of materials on the workpiece has been made to highlight the parameters that results in better surface finish. It also describes the optimization of the die-sinking micro-EDM process with multiple performance characteristics based on Taguchi method with the grey relational analysis and Analysis of Variance (ANOVA). Further, the mathematical modeling of the die-sinking micro-EDM process with multi regression analysis, using SPSS software has been discussed. It presents the
predicted non-linear equations for the process parameters and identifies the most influencing factors.

Chapter five summarizes the conclusions derived from the experimental analysis and suggests possible work that can be undertaken in the future.