Title of the Ph.D. (Engg.)Thesis: Analysis and Optimization of Performance of Electro Discharge Machining of Advanced Engineering Materials

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ABSTRACT

Machining materials that are hard to manufacture, including ceramics and diverse metal alloys, presents new challenges in a variety of fields. The machine tool, aerospace, automotive, electrical, and electronics industries all employ ceramics. These hard-to-machine materials cannot be machined using traditional machining techniques including turning, milling, and grinding.

There is a lot of possibilities for producing a product using electrically non-conductive materials using some unconventional machining techniques. Despite being widely used to process electrically non-conductive materials, ultrasonic machining (USM) has some intrinsic disadvantages, such as tool wear, high capital costs, and the potential for tool bending. Abrasive water jet machining (AWJM) is a risky procedure that requires a significant upfront investment and continuous maintenance due to its high cutting speed. Furthermore, poor surface quality adds to the worse quality of the products. The electrical diamond wheel grinding process has some disadvantages, such as the requirement for costly equipment, continuous maintenance, and skilled personnel, even if it may be used to machine electrically non-conductive materials. In laser beam machining, a strong monochromatic light source is employed. However, the procedure is exceedingly expensive, and the goods' quality is lowered by the development of a wide, undesired heat-affected zone. Traditional mechanical machining techniques find it extremely challenging to create fine forms free of micro-cracks, which is one of the fundamental needs of machining ceramic materials.

Although the electro-discharge machining (EDM) method has been extensively studied in several fields of study, there is still little use for it in milling electrically non-conductive materials. Many basic issues still need to be resolved before the parametric implications on the machining characteristics of the EDM process can be thoroughly investigated and analysed. By doing this, the process criterion goals for machining operations on ceramics that are electrically non-conductive will be maximized.

It is evident from the literature review that relatively few studies have been published to examine the machining properties of EDM technique when sophisticated technical materials like ceramics and shape memory alloy (NiTiNOL) are being machined. Additionally, a thorough experimental study is required to determine whether EDMing advanced engineering materials in various settings is feasible. The current investigation's goals are as follows in order to address machining issues that arise when sophisticated technical materials are being machined:

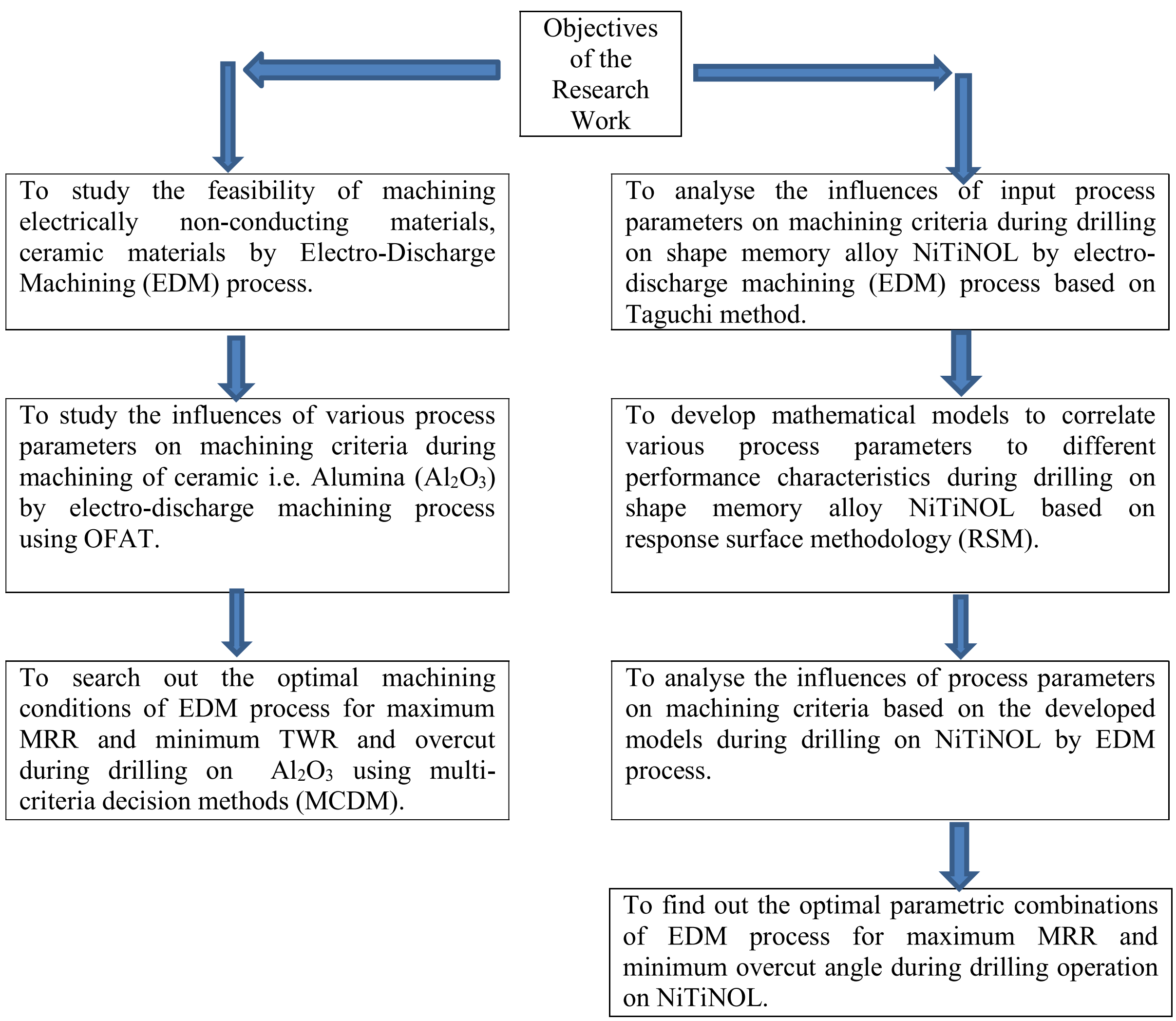
(i) To study the feasibility of machining electrically non-conducting materials such as ceramic materials by electro-discharge machining (EDM) process.

(ii) To study the influences of various process parameters such as peak-current, pulse on-time and flushing pressure etc. on material removal rate (MRR), tool wear rate (TWR)and overcut (OC) during machining of ceramic i.e. Alumina (Al_2O_3) by electro discharge machining process.

(iii) To analyse the influences of input process parameters such as polarity, peak current, pulse on-time, spark time etc. on MRR and Taper angle during drilling on shape memory alloy such as NiTiNOL by electro-discharge machining (EDM) process based on Taguchi method.

(iv) To develop mathematical models to correlate various process parameters to different performance characteristics e.g. MRR and overcut during drilling on shape memory alloy such as NiTiNOL based on response surface methodology (RSM).
(v) To analyse the influences of many process parameters such as gap voltage, peak current, pulse on-time etc. on MRR, overcut based on the developed models during drilling on NiTiNOL by electro-discharge machining (EDM) process.
(vi) To search out the optimal machining conditions of EDM process for maximum MRR and minimum TWR and overcut during drilling operation on Alumina using multi-criteria decision methods (MCDM).
(vii) To find out the optimal parametric combinations of EDM process for maximum MRR and minimum taper angle during drilling operation on NiTiNOL based on Taguchi method as well as to search out the optimal machining conditions of EDM process for maximum MRR and minimum overcut during drilling operation on NiTiNOL based on the developed models by using distance optimality technique of RSM.

The objectives of the present research work are shown graphically as below:



The findings for the EDMing of advanced engineering materials such ceramics and NiTiNOL have been compiled based on the findings of experimental tests, analysis, and the impacts of different process parameters on machining characteristics. Nevertheless, given the constraints of time and resources, the following conclusions can be made:

EDM process can be used for cutting as well as drilling advanced engineering materials such as electrically non-conducting materials e.g. Alumina and shape memory alloy e.g. NiTiNOL.

As far as material of assisted electrode is concerned, copper is found best suited for EDM drilling of Al_2O_3. In comparison to cylindrical tool, drill bit is appropriate for machining of Al_2O_3 because of better flushing as well as removal of the machined by-products through the flute of drill bit. EDM oil is best suited for machining of Al_2O_3 due to its ability to dissociate into hydro-carbons, which helps in formation of pyrolytic carbon layer for carrying out the further machining.

Peak current (Ip), on time (Ton) and flushing pressure are the most influencing parameters on the performance characteristics e.g. material removal rate (MRR), tool wear rate (TWR) and overcut (OC). From the experimentation, it has been observed that increasing peak current (Ip) decreases MRR and TWR but increases overcut (OC), similarly increasing on time (Ton) decreases MRR and TWR but increases overcut (OC). In case of flushing pressure all the three responses i.e. MRR, TWR and overcut (OC) decreases with increase in flushing pressure value. From the MCDMs results it has been observed that peak current (Ip) of 1 A, on-time (Ton) of 3 µs and 5 kg/cm2 of flushing pressure is the best parametric combination for maximum MRR and minimum OC and TWR when machining of Alumina (Al_2O_3) in EDM process.

In straight polarity both MRR and taper angle are found more compared to reverse polarity during EDMing of NiTiNOL. Peak current increases MRR because it produces more intense sparks that erode the material faster. MRR increase with pulse on-time and sparking time whereas peak current and sparking time increase taper angle.

According to the ANOVA test of Taguchi method polarity and pulse on-time are significantly most influential process parameters during drilling on NiTiNOL by EDM process. MRR increases with the increase of peak current but decreases with increase in pulse on-time from 30 to 40 µs due to abnormal sparking on debris particles during machining of NiTiNOL by EDM process based on response surface methodology (RSM). With increase in servo voltage from 30 to 45V MRR increases up to a certain level (0.2 mm^3/min) and then decreases when servo voltage increases from 45 to 75V. Based on the S/N ratio of Taguchi method, maximum MRR and minimum taper angle are found at 12A/20µs/6s and 12A/30µs/4s respectively during machining of NiTiNOL by EDM process

After analysing thoroughly various graphs as plotted for overcut, it is evident that overcut increases with corresponding rise in peak current while other parameters remaining fixed at constant level. In the lower ranges of pulse on-time overcut goes on increasing while other machining parameters including peak current are maintained at fixed value. With increase in servo voltage OC increases for all pulse on-time and peak current. Peak current and pulse on-time influence significantly MRR and overcut phenomenon while drilling of NiTiNOL by EDM process based on RSM. The developed models for MRR and OC applying experimental data have been proved to be accurate as well as collaborative at 75% confidence level.

From the single-objective optimization results it is clear that maximized MRR is found at 10 A/ 22 µs/45V and minimized OC is obtained at 6 A/ 30 µs/ 64 V while drilling of NiTiNOL by EDM process based on RSM. Also, according to the multi-objective optimization result, both maximized MRR and minimized OC are found simultaneously at the parametric combination of 5 A peak current, 26 µs pulse on-time and 54 V servo voltage.

The outcomes of the present research work have been exhibited as follows:

Outcomes of the present research work

The machining electrically non-conducting materials, ceramic materials (e.g. Alumina) can be machined successfully in Electro-Discharge Machining (EDM) process with the help of assisting electrode method.

Peak current (Ip), on time (Ton) and flushing pressure are found as the most influencing factors on the performance characteristics of EDM e.g. MRR, TWR and OC during machining of ceramic i.e. Alumina (Al_2O_3) using OFAT.

With the use of different MCDM techniques such as TOPSIS, MOORA and SAW, I_p of 1 A, T_{on} of 3 µs and 5 kg/cm^2 of flushing pressure are found as the best parametric combination for obtaining maximum MRR and minimum OC and TWR when machining of Alumina (Al_2O_3) in EDM process by using copper as an assisting electrode.

Polarity and pulse on-time are significantly the influential process parameters during drilling on NiTiNOL by EDM process based on Taguchi method. MRR and taper angle are found more in straight polarity compared to reverse polarity during EDMing of NiTiNOL. Maximum MRR and minimum taper angle are found at 12A/20µs/6s and 12A/30µs/4s respectively.

Mathematical models have been developed to reflect the independent, quadratic and interactive effects of Ip, Ton and servo voltage on MRR and OC during drilling on shape memory alloy NiTiNOL in EDM process based on RSM.

Overcut increases with corresponding rise in Ip. In the lower ranges of pulse on-time overcut goes on increasing including peak current are maintained at fixed value. OC increases with increase in servo voltage for pulse on-time and peak current.

Both maximized MRR and minimized OC are found simultaneously at the parametric combination of 5A peak current, 26µs pulse on-time and 54V servo voltage during drilling on NiTiNOL based on RSM.

In order to explain the influence of different process parameters for achieving favourable control over electro-discharge machining, it is clear that the different stages of experimentation and analysis based on the Taguchi method as well as quantitative modelling based on response surface methodology (RSM) as obtained through the current research work will be quite helpful. The results of studies on the electro-discharge machining of electrically non-conductive ceramic Alumina using an aided electrode will also give manufacturing companies helpful recommendations for enhancing EDM's performance characteristics while machining other ceramic materials. The results of research on the shape memory alloy NiTiNOL will assist the manufacturing sector in selecting the best parametric through the use of electro-discharge machining. To choose the ideal parametric parameters for obtaining the best results when machining electrically non-conducting ceramic materials like Alumina and NiTiNOL, RSM and MCDM-based multi-objective optimal outcomes would be very beneficial.

Hence, in order to explain the influence of various process parameters for achieving favourable control over electro-discharge machining of advanced engineering materials, such as alumina and NiTiNOL, it is clear that different stages of experimentation based on different design of experiment (DOE) and analyses on the current research work will be quite worthwhile. The research findings will give manufacturing scientists and applied researchers' important direction for establishing a special platform for precisely and quickly machining advanced engineering materials like ceramics and shape memory alloy.

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