Ultrasonic machining (USM) is a non-conventional mechanical material removal process in which material is removed by repetitive impact of abrasive particles carried in liquid medium on the work surface, by a shaped tool, vibrating at ultrasonic frequency. The application of ultrasonic energy for machining of engineering materials was first reported by Wood and Loomis in 1927. However, American engineer Lewis Balamuth invented the USM process in 1945. USM has been variously termed as ultrasonic drilling; ultrasonic cutting; ultrasonic dimensional machining; ultrasonic abrasive machining and slurry machining. From 1950s it has been commonly known as ultrasonic impact grinding or USM. In ultrasonic machining process, the converter transforms electrical energy into high frequency mechanical vibrations. The process parameters of USM includes the static pressure, vibration amplitude, vibration frequency, rotational speed of tool for rotary USM (RUM), diamond grit concentration, grit size, diamond and bond type, slurry concentration and coolant etc.

Some of the advantages of USM are high accuracy and good surface finish, no heat generation during machining, capability of drilling circular and non-circular holes on very hard materials, no thermal effects on mechanical workpiece and ability to machine electrical conductive as well as non-conductive materials can be machined. Unlike other non-traditional processes such as laser beam machining and electro-discharge machining etc., ultrasonic machining process generates the work surface with no thermal damage and low level of residual stress, which is important for the survival of brittle materials in service. The newest and most exciting class of advanced engineering materials are alumina, zirconia, silicon carbide, silicon nitride, boron carbide and boron nitride, etc. those can be machined by USM. There is tremendous need of ultrasonic machining and it has great potential application in the field of advanced manufacturing. The in-depth parametric analysis of USM process is highly demanded for improving the machining performance during generating the non-circular hole geometry on advanced engineering materials such as ceramics.
Research works on the area of ultrasonic machining to make it more efficient material removal processes for advanced materials have been demanded to fulfill the need of modern manufacturing industries. Although good number of research activities have already been carried out on ultrasonic machining process, a research in optimal selection of various dominant process parameters are still needed for the successful adoptability of the ultrasonic machining process in fulfilling the material machining needs of the modern manufacturing industries.

Keeping the above considerations in view, the objectives of the present research work have been modulated as follows:-

(i) To analyse the machining characteristics of ultrasonic machining on ceramics based on the material removal mechanism of ultrasonic machining process and also to identify the effect of various machining parameters on the machining performance of USM process for selecting the range of different process parameters.

(ii) To develop the work holding unit for performing drilling operation using USM experimental set up and also develop the tool holding arrangement for fixing circular and non-circular tools in such a manner that the system is capable for carrying out experimentations.

(iii) To carry out basic experimental studies on USM process for machining various type of engineering ceramics for analyzing the effects of various dominant process parameters i.e. abrasive grit size, slurry concentration, power rating, feed rate and slurry flow rate on the important machining criteria i.e. material removal rate, surface roughness, hole taper and radial overcut.

(iv) To plan and carry out experimental studies as per Taguchi method on USM process for machining high alumina ceramics for analyzing the effects of process parameters on material removal rate, surface roughness, hole taper and radial overcut.

(v) To determine the optimal parametric combinations of grit size, slurry concentration, power rating and feed rate based on Taguchi
methodology for maximum material removal rate, minimum surface roughness, hole taper and radial overcut during ultrasonic machining circular hole on ceramics.

(vi) To perform analysis of variance (ANOVA) to find out percentage contribution of USM process parameters on material removal rate, surface roughness, hole taper and radial overcut.

(vii) To determine the optimum parametric combination of grit size, slurry concentration, power rating and feed rate based on single-objective optimization and multi-objective optimization using Taguchi methods with Principal Component Analysis for maximum material removal rate, minimum surface roughness, hole taper and radial overcut during ultrasonic machining of alumina, Al₂O₃.

(viii) To study the influence of predominant USM process variables on the performance characteristics during ultrasonic drilling of alumina ceramics based on the observations of micrographs of the machined job samples.

(ix) To plan and carry out experimental studies on USM process based on Response Surface Methodology for analyzing the influence of process parameters on material removal rate and surface roughness during machining of high alumina ceramics.

(x) Development of mathematical models to establish relationship between USM process parameters for analyzing the influence of parametric combinations on material removal rate and surface roughness.

(xi) To determine the optimal parametric combinations of abrasive grit size, slurry concentration, power rating, tool feed rate and slurry flow rate based on RSM for maximum material removal rate and minimum surface roughness during ultrasonic machining of high alumina.

(xii) To carry out verification experiments and ANOVA for testing adequacy of the additive models for selecting parametric combinations of USM to achieve desired MRR and surface finish at various designed considerations.
(xiii) To perform the experimental studies on ultrasonic machining characteristics and analyze the influences of different parametric combinations e.g. grit size, slurry concentration, power rating, tool feed rate and slurry flow rate on machined hexagonal hole profile accuracy.

(xiv) To study the effects of parametric combinations on profile accuracy based on micrographs of machined hexagonal hole generated by USM.

(xv) To develop mathematical models based on RSM to establish relationship between different machining parameters and various factors of hole profile accuracy such as angular deviation at corners, dimensional deviation across corners and dimensional deviation across flats as well as analyse the profile accuracy of hexagonal hole based on developed models with predominant process parameters of USM.

(xvi) To carry out single objective optimization as well as multi-objective optimization based on developed models and analyze improvement of geometrical profile accuracy of drilled hexagonal holes on ceramics by USM.

The thesis has been divided into six chapters. Brief description of the contents of each chapter has been given as following:

**Chapter 1** contains introduction to ultrasonic machining methods, their comparative features, applications and relative merits and demerits. Various aspects of ultrasonic machining (USM) have been detailed; need of USM, applications of ultrasonic energy and fundamentals of USM. Extensive review on literatures has been presented on the development of ultrasonic machining and recent reports from researches in the areas of conventional ultrasonic machining processes.

**Chapter 2** highlights the working principle of USM, mechanism of material removal with some literature and basic influences of some parameters during
USM process. It also presents a model of material removal mechanism in USM process.

**Chapter 3** details the description of various components of USM, developed tools, fabrication of tool holding plates, abrasive grits and slurry recirculation system. It also contains electrical and power specification of USM and typical values for USM operating parameters.

**Chapter 4** highlights the results of experimental investigation for optimal parametric combination of process parameters such as abrasive grit size, slurry concentration, power rating and tool feed rate during ultrasonic machining on alumina ceramics with tubular tools using Taguchi method of robust design. It also contains results of multi-objective optimization of USM process parameters applying Taguchi method with Principal Component Analysis.

**Chapter 5** highlights the observations based on experimental investigation in to the influence of ultrasonic machining process parameters such as abrasive grit size, slurry concentration, power rating, tool feed rate and slurry flow rate on material removal rate and surface roughness on workpieces using Response Surface Methodology (RSM).

**Chapter 6** contains detail analysis of experimental results in the context of profile accuracy of the generated hexagonal hole by USM. It also contains results and analysis based on developed mathematical relationships utilizing Response Surface Methodology for determining the influence of various process USM parameters such as grit size, slurry concentration, power rating and feed rate on different factors of profile accuracy such as angular deviation at corners, dimensional deviation across corners and flats of the hexagonal holes.

**Chapter 7** is all about the conclusions of this research work. This chapter also highlights the limitations of the study and scope for future work in this area. This chapter is followed by References.
From the various experimental analysis and test results, genuine attempts have been made to justify the uniqueness of the research work in exploring out the most dominant parametric combinations on USM process variables for achieving desired controlled process combination criteria yield during ultrasonic machining of engineering ceramics. It is expected that the research work on multi-objective optimization of control factors in ultrasonic machining process on ceramics will be useful for enabling and understanding ultrasonic machining of engineering ceramics in modern manufacturing industries. The observed values can also be used as information for the technical guidelines to carry out further research activities in the areas of ultrasonic machining of ceramics for fabricating ceramic die and other ceramic components. Research activities on optimization of USM based on RSM will open up many challenging possibilities such as selection of controlling parameters for production of non-circular holes and cavities on ceramics with geometrical and dimensional accuracy. Some of the important findings related to profile accuracy of machined jobs during USM of ceramics might be effectively utilized during USM operation for better design of tools.