Advanced engineering materials, such as metal matrix composites, super alloys and engineering ceramics are the building blocks of advanced technology. The quest of manufacturing processes has always been to sustain and/or increase productivity while keeping pace with new materials of high strength, complexity in shape and size, higher demand for product accuracy and surface finish. Conventional edged tool machining is uneconomical for such materials. Moreover, the degree of accuracy and surface integrity attainable is poor, and many times cannot be accepted.

The new methods of manufacturing are expected to meet the above mentioned demands while considering the factors of economics and time along with minimum human interference so as to lead towards automation. Wire Electric Discharge Machining (WEDM), provides an effective solution in machining of such hard and difficult to machine materials, provided they are electrically conductive. It has grown tremendously and gained a broader base due to advantages of being unaffected by the material hardness, absence of mechanical cutting force, high accuracy and the ability to achieve complex work piece profile as well as unmanned machining in spite of high machining cost. Electric Discharge Machining (EDM) is basically a thermal process wherein erosion of material is result of high temperature provided by the sparks. The parameters such as voltage, current and spark time predominantly monitor the intensity of incident energy. The rupture/ removal of material depend upon the temperature developed due to energy-density and the interaction-time. Excessive temperature leads to post process issues such as heat affected zone, recast layer and cracks.

Fourier's law is appropriate in describing heat conduction in most common engineering situations however, it breaks down in situations involving very short times of the order of micro or nano seconds and high heat fluxes. Since in case of modern precision EDM's too, the pulses are narrow but of reasonably high intensity, this diffusion law gives inaccurate and inappropriate results. Therefore a transient hyperbolic heat conduction thermal model has been developed. It predicts the temperature for assessing the energy interaction rate; which can be used as guideline
by further researchers to understand the implications of signature due to temperature and the process parameters monitoring it. The importance of current research lies on the signature analysis of pulses, to assess the surface characteristics from pulse energy which would enable the future development. In order to understand the intricacies of pulses and to quantify number of sparks a modified circuit has been developed. The temperature profile obtained leads to estimation of volume of material eroded. Finally, the close validation of the temperature through monitoring structural changes justifies the science involved in the process.

Tungsten carbide (WC) is one of the important materials for tool and dies industry, due to its high hardness, strength and wear-resistance over a wide range of temperature. Carbide is a sintered material made up of carbide granules (such as tungsten carbide or silicon carbide) that are held together by a binder such as cobalt. The binders glue and pull the carbide granules together under great tension. The problem to EDM machining is that the carbide granules resist the flow of current while the binder material is highly conductive. Thus, the current from the EDM spark flows through the carbide grains on a tiny spot on the surface. The water vapour bubble caused by the spark collapses violently and the deionized water flashes away the melted cobalt and pieces of WC grains. This is typical erosion characteristics, i.e. the thermal energy leads to rupture of bond between cobalt and carbide granules. These free carbide granules also contribute to the recast layer. The complexity in erosion of WC has motivated for its selection for current work. Moreover, due to its heterogeneous characteristics, hyperbolic heat transfer model would justify the reality.

In tune with the issues raised above, a hyperbolic heat conduction model (considering thermal relaxation time) for erosion in EDM has been developed. Subsequently scientifically planned experiments (Taguchi Orthogonal Array) on various grades of tungsten carbide are carried out in order to understand their erosion characteristics. A modified circuit has been developed, which leads to acquisition of current and voltage signatures. These acquired signatures are further analyzed using a circuit in LABVIEW to estimate the RMS current, voltage and number of pulses. Further ANOVA is carried out based on VMRR, MRR and surface roughness for obtaining the optimum machining condition for all the materials processed. Confirmatory tests for various grades of carbide are carried out, in order to compare the values predicted by the present model with the values obtained experimentally. A detailed analysis of
the thermal model developed is carried out considering materials used for experimentation viz. copper and tungsten carbide, which can lead to confirming the adequacy of the model. Some theoretical curves are plotted using the model, which indicate the significance of thermal relaxation time and its effect on the process. Relevant literature survey has been carried out. Similarly the samples processed are examined using a microscope to get an idea about surface integrity (qualitatively).

**Organization of the Thesis**

The primary objective of the present work is to model the erosion characteristics of material while using WEDM and corroborate the experimental results. Moreover it is required to evaluate feasibility of machining tungsten carbides with process optimization as well as process automation.

Chapter 1 deals with an introduction to EDM/WEDM process. Chapter 2 describes outcome of literature survey considering about sizable number of related papers in the field of machining, using EDM/WEDM. Chapter 3 is devoted for development of mathematical model for erosion characteristics in an EDM/WEDM considering axis symmetrical transient hyperbolic heat conduction equation. Chapter 4 describes the details of experimental setup, modified circuit, signature analysis in LABVIEW, pilot experiments carried out in order to finalize the range of processing parameters along with scientifically planned and performed experimentations. Chapter 5 has been devoted to process optimization for surface roughness and MRR/VMRR by using Taguchi method. In Chapter 6 theoretical temperatures at the various depths and radial distance are computed by using the thermal model developed and discussed in Chapter 3. These theoretical temperature values obtained are compared with experimental values obtained. Further Results obtained, their discussion, inferences drawn from experimentation and optimizations are also presented. In Chapter 7 conclusions drawn, along with the scope for future work are suggested.

**Keywords**: WEDM, Tungsten Carbide (WC), Material Removal rate (MRR), Volumetric Material Removal rate (VMRR), Surface roughness, Heat affected zone (HAZ), surface integrity, Spark on time (Ton), Spark off time (Toff), Voltage pulse, Current pulse, Hyperbolic heat conduction equation, Relaxation time, Laplace Transformation, Hankel Transformation, Taguchi technique.