CHAPTER 3

EXPERIMENTAL SET-UP AND
PROCESS PARAMETER SELECTION

3.1 MACHINE TOOL

The experiments were carried out on a Wire Electro Discharge Machine (WEDM) ELECTRA “ECOCUT” of M/S Electronica Machine Tools Ltd. installed at Computer Aided Manufacturing Lab of Mechanical Engineering Department, KLN College of Engineering, Pottapalyam, Tamilnadu, India.

The specifications of the machine are:

- Design : Fixed column, Moving table
- X x Y travel : 250 x 350 mm
- Max. work height : 200 mm
- Max. table size : 370 x 600 mm
- Max. cutting speed : 70 mm / min
- Taper : ± 5° over 100 mm
- Best surface finish : 1.2 µm R_a
- Wire electrode dia : 0.25 mm (std) 0.15, 0.20 (optional)
- Generator : ELPULS-40 A DLX
- Controlled axes : X, Y, U, V
  - simultaneous/independent
- Interpolation : Linear & Circular
- Input power supply : 3 phase, AC 415 V, 50 Hz
- Connected load : 10KVA
- Average power consumption: 6-7 KVA
Figure 3.1 Photograph of the experimental machine
Figure 3.2 Closer view of wire and the work piece
Figure 3.3 Layout of the machine
3.2 WORK PIECE

Following materials are chosen throughout the experiments.

Table 3.1 Materials and their compositions

<table>
<thead>
<tr>
<th>S. No</th>
<th>Material</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>D2 tool steel</td>
<td>C-1.5%, Cr-12%, V-0.6%, Mo-1%, Si-0.6%, Mn-0.6%, remaining Fe.</td>
</tr>
<tr>
<td>02</td>
<td>Inconel 800</td>
<td>C-0.096%, Cr-20.096%, Mn-0.501%,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Al-0.302%, Mo-0.335%, Ni-34.991%,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fe-42.821, Ti-0.304, W-0.066, V-0.027%, C0-0.07%</td>
</tr>
<tr>
<td>03</td>
<td>OHNS die steel</td>
<td>C-0.325, Si-0.8%, Mn&lt; 0.5, Cr- 4.5-5.5%,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mo-1-1.5%, V-0.8-1.2% remaining Fe</td>
</tr>
<tr>
<td>04</td>
<td>Cemented Carbide</td>
<td>Cobalt-12%, TiC + TaC-3%, WC-85%</td>
</tr>
<tr>
<td>05</td>
<td>Al-Al₂O₃ MMC</td>
<td>Si-0.4%, Cu-0.15%, Ti-0.15%, Cr-0.04%,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S-0.05, Fe-0.75, Mg-0.8%, Mn-0.15%,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zn-0.255, Al-remaining, 20%-Al₂O₃-particle</td>
</tr>
<tr>
<td>06</td>
<td>304 SS</td>
<td>Cr-18.37%, Ni-8.19%, Mn-1.8%, Cu-0.585,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Si-0.54%, P-0.039%, N-0.037%, C-0.021%,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>S-0.0195, Remaining Fe</td>
</tr>
</tbody>
</table>

All the above materials are used in extreme load conditions such as hot work forging, extrusion etc. The applications of these materials are varied such as manufacturing of punching tools, mandrels, mechanical press forging die, plastic mould and die-casting dies, air craft landing gears, helicopter rotor blades, shafts, space crafts etc.
3.2.1 Significant Properties and Applications

For cemented carbide, the carbide is sintered material made up of carbide granules (such as tungsten carbide or silicon carbide) that are held together by a cobalt binder. Especially, for WEDM grades, exists Ni binder and also a lot of additional elements are possible to prevent depletion of the binder.

Actually the binders glue and pull the carbide granules together under great tension. The problem to EDM machining is that the binder is highly conductive while the carbide granules resist the flow of current. Thus the current from the EDM spark flows through the binder and around the carbide granules. The spark vaporizes the cobalt and disintegrates the carbide grains on a tiny spot on the surface. The water vapour bubble caused by the spark collapses violently and the de-ionized water flushes away the melted cobalt and pieces of WC grains. Then the whole process is repeated. In this work the WEDM tests are carried out on cemented carbides.

For Inconel 800 Nickel base super alloys are extensively used in high temperature applications such as gas turbines, electric power generation equipment, nuclear reactors and high temperature chemical vessels. Inconel 800 is a nickel base super alloy with a high content of iron, chromium and niobium, strengthened mainly with Ni$_3$N. It is widely used, mostly in gas turbine discs. The properties of these super alloys, such as temperature strength, high hardness, low thermal diffusivity, presence of highly abrasive carbide edge, make them extremely difficult to machine.

Metal matrix composites (MMCs) are newly advanced materials with light weight, high specific strength, good wear resistance and a low thermal coefficient. They are extensively used in Aero space and Automobile
industry. Greater hardness and reinforcement make it difficult to machine using traditional techniques. The use of traditional machinery to machine hard composite materials causes serious tool wear due to the abrasive nature of reinforcing Al\textsubscript{2}O\textsubscript{3} particles. Therefore WEDM is the best choice for machining composite materials.

OHNS steels also known as chromium molybdenum alloy steel is oil hardening steel of relatively high hardening ability and is among the most widely used versatile machinery steels. The chromium content provides good hardness penetration and the molybdenum imparts uniformity of hardness and high strength. This grade is especially suitable for forging as it has self scaling characteristics. It responds readily to heat treatment and is comparatively easy to machine in the heat treated condition. In the heat treated condition it has high tensile strength combined with good ductility and resistance to shock.

3.3 PREPARATION OF SPECIMEN

The work piece materials of 20 mm flat plate is mounted on the Electronica Ecocut WEDM machine tool (Figure 3.1) and specimen of 60x20x20 mm size are cut out.

The closer view of the specimens is shown in Figure 3.4.
Figure 3.4 Closer view of the specimens

3.4 MEASUREMENT OF EXPERIMENTAL PARAMETERS

The discussions related to the measurement of WEDM Experimental Parameters, Material Removal Rate (MRR), Surface Roughness are presented in the following

3.4.1 Material Removal Rate (MRR)

For WEDM, MRR is a desirable characteristic and it should be high as possible to give least machine cycle time leading to increased productivity. In the present study MRR is calculated as

\[
MRR = \frac{\text{Weight loss due to machining}}{(\text{density of the material} \times \text{machining time})}
\]
\[ MRR = \frac{(W_i - W_f)}{(\rho \times t)} \text{ mm}^3 / \text{min} \]

3.4.2 Surface Roughness

Roughness is often a good prediction of the performance of a material component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

The parameter mostly used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line and then averaging them all over the entire cut-off length. Cut-off length is the length that the stylus is dragged across the surface; a larger cut-off length will give a better average value, and a shorter cut-off length might give a less accurate result over a shorter stretch of surface.

Figure 3.5 Surface roughness measurements
In this work the surface roughness was measured by Mitutoyo Surftest SJ – 201 P (Figure 3.5). The Surf test is a shop floor type surface roughness measuring instrument, which traces the surface and calculates the surface roughness based on roughness standards and displays the results in μm.

3.5 EXPERIMENTATION

The experiments were accomplished on a Electronica Ecocut WEDM machine with 0.25 mm diameter wire. Following steps were followed in the operation.

1. The wire was made vertical with the help of verticality block.
2. The work piece was mounted and clamped on the work table.
3. A reference point on the work piece was set for setting work coordinate system. The programming was done with this as reference. The reference point was defined by the ground edges of the work piece.
4. The program was made for cutting operation of the work piece and a profile of 60 x 20 mm rectangle was cut.

While performing various experiments, the following precautionary measures were taken;

1. To reduce error due to experimental set up, each experiment during the pilot stage was repeated three times in each of the trial condition.
2. The order and replication of experiment was randomized to avoid bias; if any in the results.
3. Each set of experiment was performed at room temperature at 26±2 °C.
4. Before taking measurements of surface roughness, the work piece was cleaned with acetone.
3.6 SELECTION OF PROCESS PARAMETERS

3.6.1 Pulse on time (Ton)

The pulse on time represents the duration of time in micro seconds for which the current is flowing in each cycle. During this time the voltage, V is applied across the electrodes. The Ton setting time range available on the machine tool is 1-10 which is applied in steps of 1 unit. The single pulse discharge energy increases with increasing Ton, however, surface roughness tends to be higher. The higher value of discharge energy may also cause wire breakage.

3.6.2 Pulse off time (Toff)

The pulse off time represents the duration of time in microseconds, between the beginning of two continuous sparks. The voltage is absent during this part of the cycle. The Toff setting time range available on the machine tool is 1-10 which is applied in steps of 1 unit. With a lower value of Toff, there are more number of discharges in a given time, resulting in the increase in sparking efficiency. As a result, the cutting rate also increases. Using very low value of Toff period, however, may cause wire breakage which in turn reduces the cutting efficiency. Based on recommendations of manufactures manual (Electronica Machine Tools Ltd. 2009) and pilot experiments; an optimum range of Ton and Toff is chosen.

3.6.3 Peak current

The peak current is represented by A and it is the maximum value of the current passing through the electrodes for the given pulse. The setting peak current range available on the machine is 10-230 ampere which is applied in steps of 10 amperes. Increase in the current value will increase the cutting rate further.
3.6.4 Spark gap set voltage

The spark gap set voltage (V) is a reference voltage for the actual gap between the work piece and the wire used for cutting. The voltage range available on the present machine is 00-99 volt and is applied in steps of 1 volt.

3.6.5 Wire feed

Wire feed is the rate at which the wire electrode travels along the wire guide path and is fed continuously for sparking. The wire feed range available on the present WEDM machine is 1-15 m/min. It is always desirable to set the wire feed to maximum. This will result in less wire breakage, better machining stability and slightly more cutting speed.

3.6.6 Wire tension

Wire tension determines how much the wire is to be stretched between upper and lower wire guides. This is a gram-equivalent load with which the continuously fed wire is kept under tension so that it remains straight between wire guides. More the thickness of job more is the tension required. Improper setting may result in the job inaccuracies as well as wire breakage. The wire tension range available on the machine is 1-15 units in steps of 1.

3.6.7 Dielectric fluid

Dielectric fluid is a very important part of the WEDM process. The dielectric fluid is used to cool the wire and flush re solidified particles from the gap. Normal tap water is added to the EDM system and is cycled through a two step process. First, the water is sent through a paper filter system. Paper filters are rated in microns, which indicate the largest particle size allowed to pass through. The typical WEDM filter is between 3 and 10 microns. The fluid is pressurized into the filtration bank where it is stripped of all larger particles
and then returned to the dielectric holding tank. A set of electronic probes monitor the fluid quality in the holding tank. When the conductivity level climbs above the determined value, it is then sent to the second process.

The second process consists of a bottle called a resin cell. The resin cell contains small, round resin beads. These resin beads are electrically charged and attract the fine particles that were allowed to pass through the paper filters. Once the fluid is stripped of these fine particles, it is returned to the holding tank. The resin cell is shut off once the fluid conductivity level has been returned to the determined value. In all our experiments the conductivity of the DI-electric was in the range of 200 to 220 S (Siemens).

3.7 PILOT EXPERIMENTS

The purpose of the pilot experiments is to study the variations of the WEDM process parameters on performance measures of MRR and SR. Also it is intended to ascertain the range of different parameters required for the experimental design methodology used in this work.

The pilot experiments were performed on Electronica Ecocut WEDM machine. Various input parameters varied during the experiments are $T_{on}$, $T_{off}$, $S_v$, $I_p$, wire feed rate and wire tension. The effects of these input parameters are studied on MRR and SR. From these pilot experiments it is found that the most significant parameters affecting the performance characteristics are pulse on time, pulse off time, voltage and current while the effects of wire feed rate and wire tension are insignificant.

3.7.1 Selection of range of parameters based on pilot experiments

The range of these process parameters chosen based on pilot experiments are given in table Table 3.2. From these ranges of the process parameters, different levels of process parameters are selected for Taguchi experimental design.
Table 3.2 Ranges of process parameters

<table>
<thead>
<tr>
<th>S.No</th>
<th>Factors</th>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>Gap Voltage V volts</td>
<td>10 - 92</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>Pulse off Time Toff μs</td>
<td>1 - 8</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>Pulse on Time Ton μs</td>
<td>4 - 10</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>Applied Current A amp</td>
<td>8 - 32</td>
</tr>
</tbody>
</table>

3.8 CONCLUSION

This chapter presents the detailed discussion of the experimental set up of the present investigation and the selection of process parameters.

- A complete technical specification of the machine used in the experiment has been presented.
- Photographic views of the machine and the specimen.
- The various materials used in the experiment were presented with their chemical composition, properties and applications.
- A detailed presentation of the measurement of the experimental parameters.
- Step by step procedure of the experiment with necessary precautions to be followed during the experiment.
- Extent of the effect of various process parameters involved in the WEDM process.
- Details of pilot experiment conducted.