Investigation on Optimization of Machining Parameters on S.G.Cast iron Machining Characteristics during Wire EDM Process

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***Abstract* - Now a day's Electric Discharge Machining (EDM) is one of the most efficiently employed non-traditional machining processes for cutting hard materials, to geometrically complex shapes that are difficult to machine by conventional machines. S.G. Cast iron material has various industrial applications such as machinery, internal combustion engines, pumps and compressors. In the present work, an experimental investigation has been carried out to study the effect of voltage, current and various machining parameters like material removal rate, electrode wear and surface roughness in S.G. Cast iron. The materials used for the work were machined with different electrode materials such as copper, copper-tungsten and graphite. From in this Project output parameters such as material removal rate, electrode wear and surface roughness can be studied.**

Index Terms: **Electric Discharge Machining (*EDM), Optimization, Machining, S.G.Cast iron***

I. INTRODUCTION

Spheroidal graphite (SG) cast iron was discovered in the 1948. However, «lf coke (which is high in would have been accepted as the normal form of iron, with flake graphite iron only being discovered much later as an accident of adding S and O. This seems to have been close to the situation in China where spheroidal graphite irons were produced over 2000 years ago. The term Cast iron refers to an alloy of iron containing more than 2.0 percentage of carbon. The brittle behavior associated sulfur) had not been used for melting iron and if high purity ores had been used, then ductile iron with the cast iron is an outdated and widely held misconception which implies all cast irons are brittle and none of them are ductile in nature. Ductile iron is one form of cast iron which is ductile and it offers the designer a unique combination of high strength, wear resistance, fatigue resistance, toughness and ductility in addition to good castability, machinability and damping properties. Unfortunately these properties of SG iron are not widely well known because of the misconception about its brittle behavior.

Ductile iron or SG iron was discovered in 1948 at the American Foundry men Society Annual Conference. It was seen that by adding magnesium before pouring caused the graphite to form nodules rather than flakes. This resulted in a new material, with excellent tensile strength and ductility. Adding these mechanical properties of this material to the advantages already offered by cast iron soon led to it finding its way into virtually every mainstream area of engineering, in many cases replacing existing steel castings or forgings due to achievable cost savings. It is shown that, recent process and developments open new avenues to this family of materials.

SG iron is an alloy of iron and carbon having nodules or spheroids of graphite embedded in a ferrite-pearlitic matrix. The nodules are compact spheres and are sharp and regular. The graphite occupies about 10-15% of the total material volume and because graphite has negligible tensile strength, the main effect of its presence is to reduce the effective cross-sectional area, which means that ductile iron has tensile strength, modulus of elasticity and impact strength proportionally lower than that of a carbon steel of otherwise similar matrix structure.

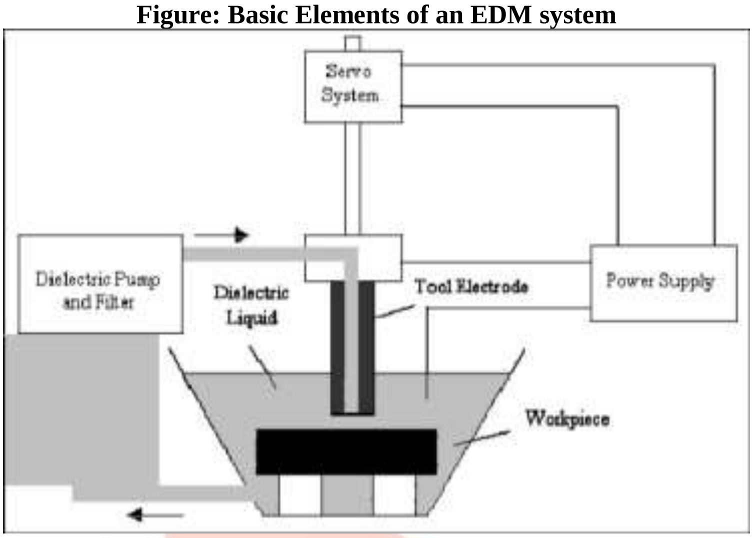
The matrix may vary from a soft ductile ferrite structure through a hard and higher strength pearlitic structure to a hard higher and comparatively tough martensitic structure. General engineering grades of ductile iron commonly have the structures which are ferrite, ferrite /pearlitic or pearlitic Controlled processing of the molten iron precipitates graphite as spheroids rather than flakes. The round shape of the graphite eliminates the material's tendency to crack and helps prevent cracks from spreading. The properties of SG iron are affected by elements like Si, Mn, Cu, Ni etc. Except carbon almost all the elements increase hardness and tensile strength. While except Si, all other elements promotes pearlite, except Si, Cu, Ni all other elements promote carbide formation.

II. EDM

Electrical Discharge Machining, commonly known as EDM is a non-conventional machining method used to remove material by a number of repetitive electrical discharges of small duration and high current density between the work piece and the tool. EDM is an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. In EDM, since there is no direct contact between the work piece and the electrode, hence there are no mechanical forces existing between them. Any type of conductive material can be machined using EDM irrespective of the hardness or toughness of the material.

Electric discharge machining (EDM) (sometimes also referred to as spark machining, spark eroding, burning, die sinking or wire erosion) is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the 'tool' or 'electrode', while the other is called the work piece-electrode, or 'work piece'.

Figure: Basic Elements of an EDM system



When the distance between the two electrodes is reduced, the intensity of the electric field in the volume between the electrodes becomes greater than the strength of the dielectric (at least in some point(s)), which breaks, allowing current to flow between the two electrodes. As a result, material is removed from both the electrodes. Once the current flow stops (or it is stopped depending on the type of generator), new liquid dielectric is usually conveyed into the inter-electrode volume enabling the solid particles (debris) to be carried away and the insulating proprieties of the dielectric to be restored. Adding new liquid dielectric in the inter-electrode volume is commonly referred to as flushing. Also, after a current flow, a difference of potential between the two electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur.

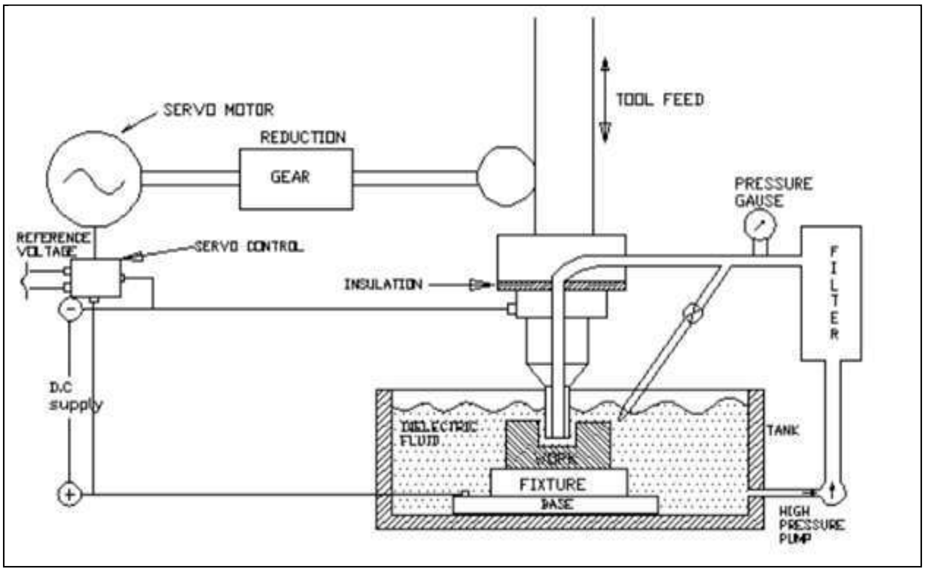
Electrical discharge machining is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques. EDM typically works with materials that are electrically conductive, although methods for machining insulating ceramics with EDM have also been proposed. EDM can cut intricate contours or cavities in pre-hardened steel without the need for heat treatment to soften and re-harden them. This method can be used with any other metal or metal alloy such as titanium, inconel etc.

EDM is often included in the 'non-traditional' or 'non-conventional' group of machining methods together with processes such as electrochemical machining (ECM), water jet cutting (WJ, AWJ), laser cutting and opposite to the 'conventional' group (turning, milling, grinding, drilling and any other process whose material removal mechanism is essentially based on mechanical forces).

Principle of EDM:

In this process the material is removed from the work piece due to erosion caused by rapidly recurring electrical spark discharge between the work piece and the tool electrode. There is a small gap between the tool and the work piece. The work piece and tool both are submerged in dielectric fluid, commonly used are EDM oil, deionized water, and kerosene.

Figure: Experimental setup



III. TYPES OF EDM

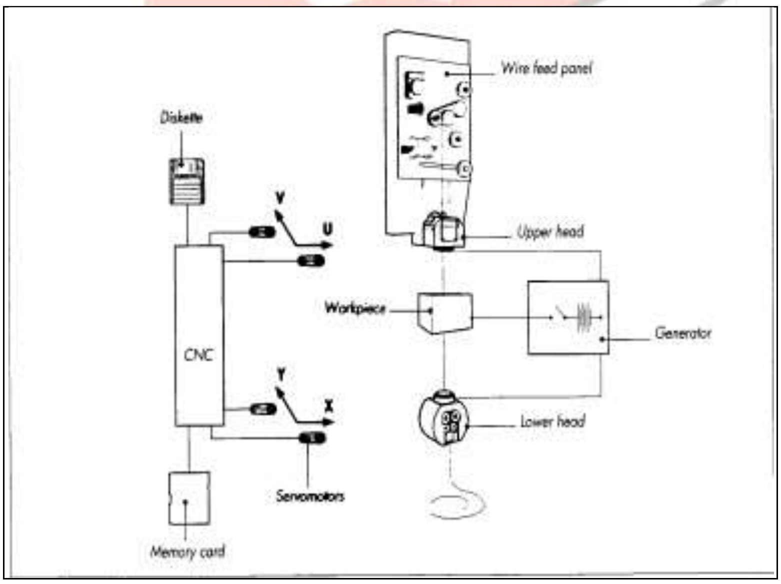
Basically there are two types of EDM

1. Wire-cut EDM
2. Die-sinking EDM (Spark EDM)

Wire EDM:

Wire EDM (WEDM) uses a fine wire electrode that is run through a pulley system while moving in a transverse direction across a work piece to affect the desired cut geometry. Electrode material composition and diameter vary according to the material selected for processing, output requirements, cost, and machine design. The dielectric fluid is typically deionized water for WEDM. A typical configuration utilized by this type of mechanism is shown in Figure 2 showing the wire feed panel where the spool of electrode wire is contained, the upper head, the work piece, and the lower head that collects the expended electrode, the spark generator, and the computer-controlled servos — used to position the work piece relative to the electrode.

Figure: Typical WEDM Setup



Wire EDM has several advantages as a machining process: it generally removes less material from the work piece than die sinker EDM and consequently results in much shorter processing times; the wire motion results in insignificant wear to the electrode due to its being continuously renewed by the pulley and spool system; and the electrode tends to be much less expensive than the complex electrodes that are frequently utilized in a die sinking application. Wire EDM's major disadvantage is the fact that it will generally only make ruled cuts. This limits the geometric complexity of machined pieces as well as the thickness of the piece being processed based on machine dimensions – specifically the maximum clearance between the upper and lower heads as seen in Figure 2.

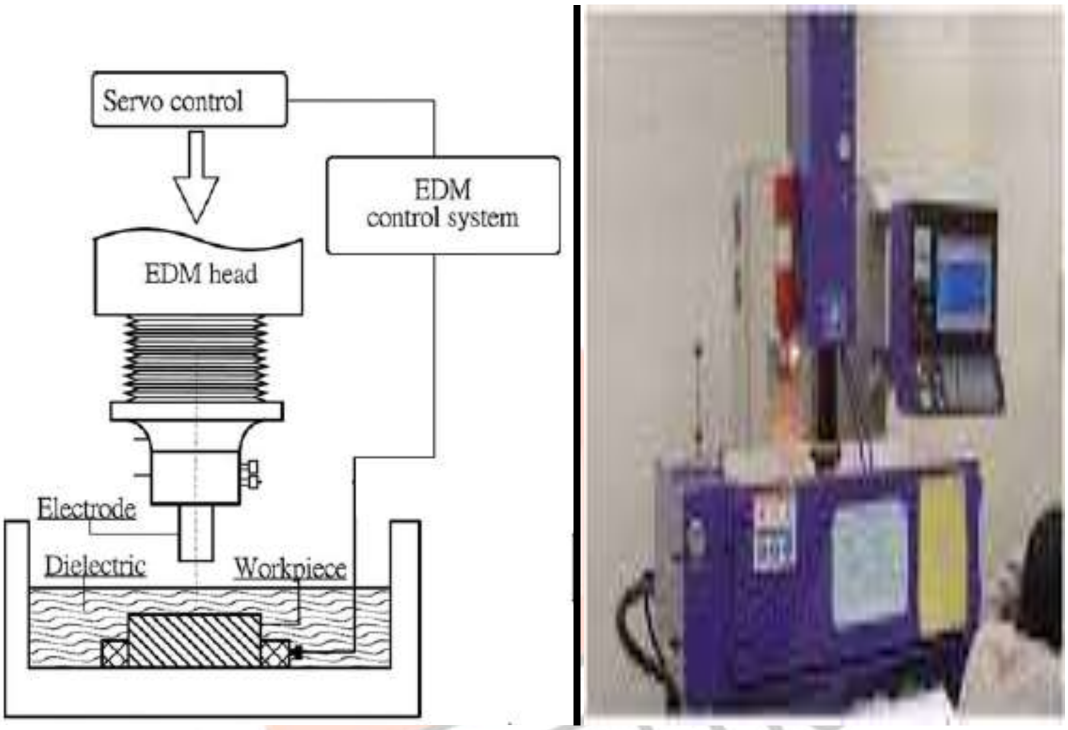
Additionally, the wire may bend or break during work piece processing, especially in sharp feature corners, resulting in a loss of feature accuracy, damage to the work piece due to the fact that the wire is under tension, and or increased processing time.

Die sinking EDM (SPARK EDM):

Die sinking EDM utilizes either metallic or graphitic electrodes that approach the work piece along the operator-selected axis. The electrode can be any shape or size desired by the operator provided it can be purchased or accurately machined, and is pressed into the work piece material. Depending on the electrode configuration and the desired cut shape, the electrode may also be spun around an axis of rotation to allow for more even wear to the electrode during work piece processing and a more even feature in the work piece. Wear to the electrode during die sinker EDM is of particular concern, as the electrode is not automatically replenished during processing as in Wire EDM. This wear can result in significant feature inaccuracies unless accounted for during processing.

Set up by the machine operator. This accounting is typically performed through the use of multistep processing utilizing multiple electrodes that are used to remove work piece material in incremental steps. Multistep processing may also be used to impart a particular finish to a work piece through the use of disparate machine settings designed to impart a particular surface finish to the completed work piece. A typical die-sinking setup is shown below in Figure.

Figure: Typical Die Sinker Setup



Die sinking EDM has the ability to render shapes along multiple axes depending on machine construction, and allows for much more complicated feature geometries than can be readily achieved using WEDM. Die sinking EDM typically uses kerosene or oil as the dielectric medium, an advantage of which is the fact that the recast layer on metal surfaces is typically much harder than that of the parent work piece. Disadvantages of die sinking EDM are typically longer processing times due to feature complexity and quantities of material removed, cost and time associated with the manufacture of complex electrodes, and the previously discussed electrode wear issues during work piece processing.

Important Parameters of EDM:

a. **Spark on-time (Ton)** **:** The duration of time (μs) the current is allowed to flow per cycle.

b. **Spark off-time (Toff)** **:** The duration of time in between the sparks generated. During this time the molten material gets removed from the gap between the electrode and the work piece.

c. **Voltage (V)** **:** It is the potential difference applied between the electrode and the work piece.

d. **Discharge Current (Ip)** **:** It is the current flowing through the electrode and is measured in amp.

e. **Duty cycle (τ)** **:** It is the ratio of Ton divided by total cycle time (Ton+Toff).

f. **Water pressure (Wp)** **:** It is amount of fluid flow through the work piece.

g. **Wire Feed (Wf)** **:** It is the speed of the wire during machining process.

h. **Wire Tension (Wt)** **:** Ovality of wire during the machining process (tightness of wire).

i. **Servo Voltage (Sv) & Servo Feed (Sf)** **:** It is constant for the particular machine

Advantages of EDM:

a. Any electrically conductive material can be machined using this process.
b. Materials which are super tough can be machined without any deformation.
c. There are no mechanical forces present between the work piece and tool.
d. Complex and intricate shape sections can be easily produced.
e. Precision works which are of high accuracy can be done.

f. Surface finish obtained will be good.

Limitations of EDM:

a. The work piece has to be electrically conductive so that electric sparks can be generated.

b. The measure of the gap that is the distance between the electrode and the workpiece is not always easily predictable, especially in case of complex geometries.

c. The material removal rate is rather low in case of EDM; hence it is limited to the production of certain sections.

d. The electrical parameters used in the EDM process have to be optimized for best results.

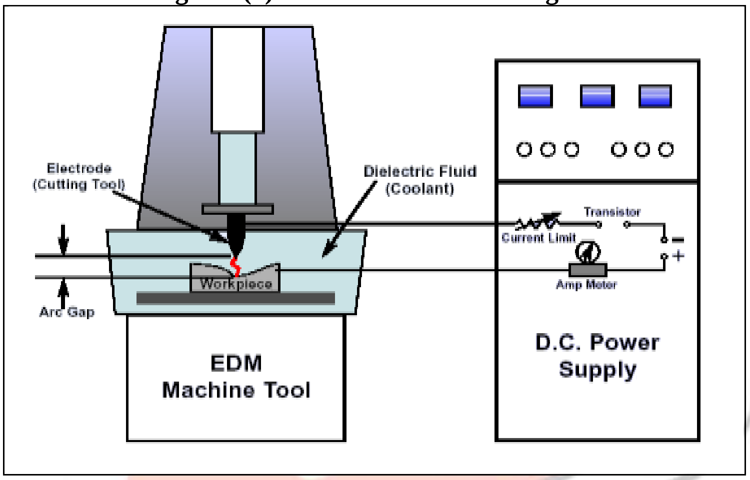
IV. OPERATION OF ELECTRO DISCHARGE MACHINING (EDM)

EDM is a thermo-electrical material removal process, in which the tool electrode shape is reproduced mirror wise into a work material, with the shape of the electrode defining the area in which the spark erosion will occur. As shown on Figure 2.2(a) and figure 2.2(b), the EDM is accomplished with a system comprising two major components:

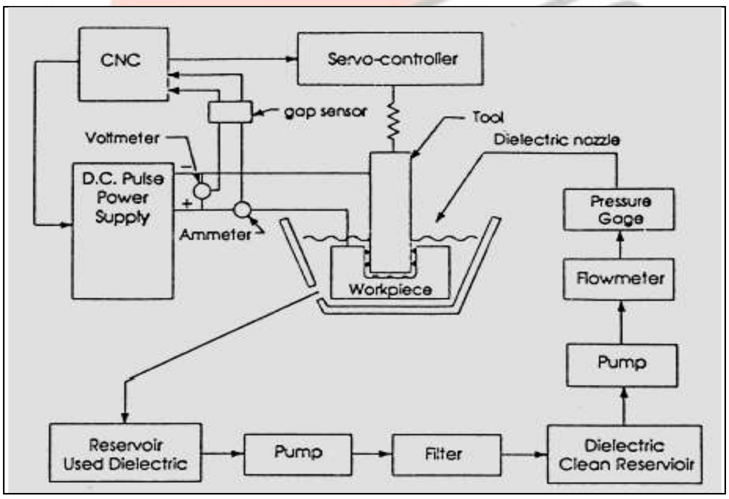
1) Machine tool
2) Power supply

The machine tool holds a shaped electrode, which advances into the work material and produces a high frequency series of electrical spark discharges. The sparks are generated by a pulse generator, between the tool electrode and the work material, submerged in a liquid dielectric, leading to metal removal from the work material by thermal erosion or vaporization.

Figure: (a) is the illustration and figure



(b) is schematic representation of basic EDM System.



Electrode:

EDM electrode materials and components consist of highly conductive and/or arc erosion-resistant materials such as graphite, copper or copper graphite. EDM is an acronym for electric discharge machining, a process that uses a controlled electrical spark to erode metal. EDM electrode materials include components made from brass, copper and copper alloys, graphite, molybdenum, silver and silver tungsten and also the moly combinations.

EDM electrodes are manufactured in variety of forms such as coated wire, tube shaped, or bar stock, depending on the EDM electrode materials used and the application. A brass electrode is easy to machine and can also be die cast or extruded for use in special applications. However, brass is not as wear-resistant as other EDM electrode materials, such as copper or tungsten, so it is typically used to make EDM wire. Copper is a common base material because it is highly conductive and strong. A copper tungsten electrode is used in resistance welding electrodes and in circuit breakers. A copper zirconium diboride electrode is

similar to a copper tungsten electrode, but has much higher erosion resistance and is more expensive to produce. A tellurium copper electrode is easy to machine and is useful in applications that require an electrode with a fine finish.
Other EDM electrode materials include graphite, silver, and molybdenum. A metal graphite electrode is the most common type of EDM electrode because it is easily machined, has high wear resistance and operating temperature capabilities, and is cost effective. A molybdenum electrode is typically used for special applications, such as small electrodes or EDM wire designed for high strength and arc erosion resistance. Silver is a highly conductive metal, and is used in conjunction with other EDM electrode materials such as erosion-resistant tungsten to make EDM electrodes for special applications.
A silver tungsten electrode may be used in deep slot applications that function under poor flushing conditions. Tungsten has a high melting point, which makes it a useful EDM electrode material in combination with more conductive metals. A tungsten carbide electrode is a combination of tungsten and carbon bound together with a metal binder. Tungsten carbide and other metal carbides are used for EDM electrode materials because they have high hardness qualities and are wear-resistant.

Flushing:

Flushing is important because it removes eroded particles from the gap for efficient cutting. Flushing also enables fresh dielectric oil flow into the gap and cools both the electrode and the work piece. Improper flushing causes erratic cutting, thus prevents the electrode from cutting efficiently. It is then necessary to remove the attached particles by cleaning the work piece. Dielectric fluid is used as flushing to assist in the removal process of particles from the work area hence giving better surface finish [9].
There are five types of flushing fluid that usually use in system in EDM; [10]. Two of the types of flushing are;

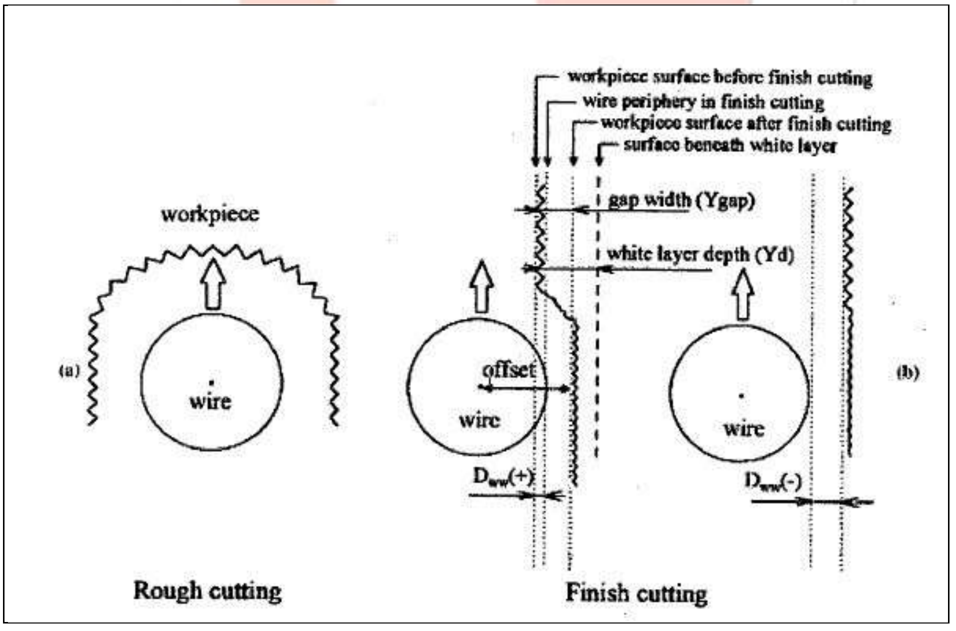
1) Pressure flushing
2) Through electrode

Wire-EDM Technology:

This logical dimension is depending on the chosen technology, which is finally machine dependent. Since the logical diameter of the tool is technology and machine dependent, therefore the offset paths of the final part can only be determined if the selected technology and machine is known. Furthermore there is no "analytical approach" to determine the logical radius of the wire Gabor Erdos (2004). It is determined based on experiments. Beside the logical diameter of the wire, there are many factors that determine the offset. In wire EDM there are basically three type of working mode:

• Roughing
• Finishing
• Surface finishing

Figure: A schematic plan view of (a) a rough (b) finish,



The number of working modes required to manufacture the same part on deferent machines is also machine dependent. The same part might require 1 roughing, 2 finishing and 3 surfaces finishing on one machine and 1 roughing 3 finishing 1 surface finishing working step on another machine.
The technological parameters- which are principally the settings of the generator- used for these manufacturing steps are also different and proprietary to the machine builders. This implies that it is rather difficult to define global working steps like in milling, because the definition of the technology of these working steps varies from machine to machine.

V. EXPERIMENTAL PROCEDURE

The experimental procedure for the project work can be listed as:

1) Specimen preparation

2) Surface finish
3) Chemical composition
4) Microstructure

Specimen Preparation:

Figure: Specimen Preparation

Specimen – Rectangular Block of 300*100*28

Specimen	C%	MN %	SI %	S %	P %	MG %
BLOCK	3.3	0.46	2.65	0.088	0.088	0.091

Surface Finishing Process:

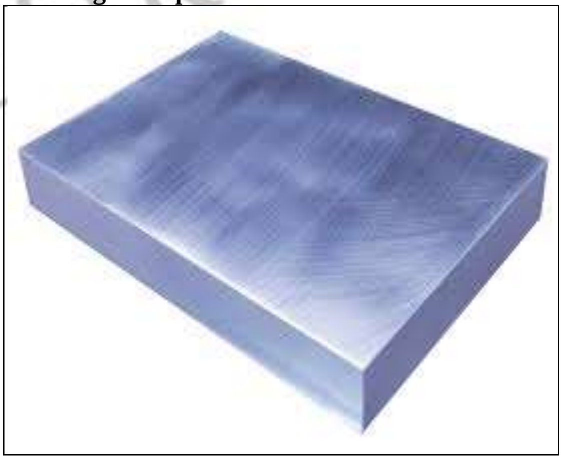
Specimen – Rectangular Block of 65*40*28 into smooth Rectangular Block of 61.5*34.5*23.5

- Milling Machine

Apply the milling operation to the rectangular block thickness upto 2mm removing material to form semi finished rectangular surface and then do the grinding operation for the remaining material in order to get the good surface finish.

Figure: Specimen

Figure: Specimen



Wire EDM Machining:

- Experimental set up

The experiments were conducted using the Electric Discharge Machine, model ELECTRONICA -ELECTRAPLUS PS 50ZNC (die sinking type) the polarity of the electrode was set as positive while that of work piece was negative. The dielectric fluid used was EDM oil (specific gravity-0.763). The EDM consists of the following parts:

i. Dielectric reservoir, pump and circulation system.

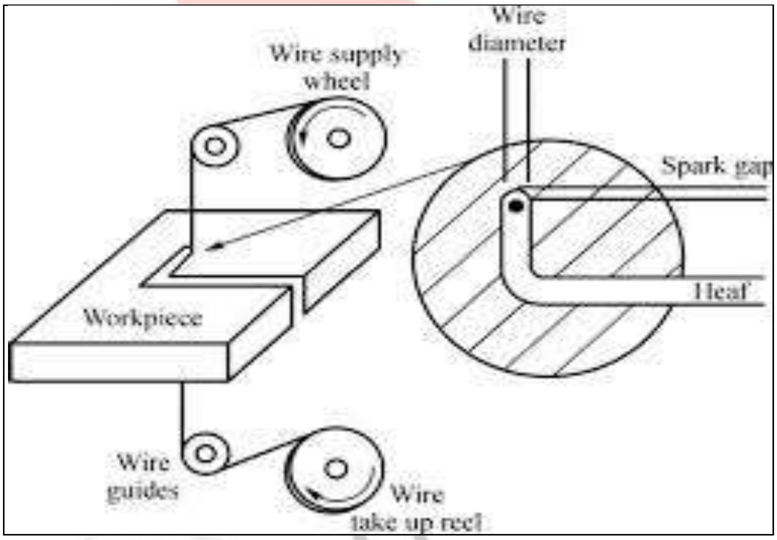
ii. Power generator and control unit.

iii. Working tank with work holding device.
iv. X-Y working table
v. The tool holder
vi. The servo system for feeding the tool.

Figure: Dielectric reservoir

Figure: Control unit of EDM machine

Figure: EDM Mechanism



- For giving the input to the EDM machine first prepare profile on auto cad software and convert to machine program by using software is L Cam software then it will perform the desired operation.
- The brass coated copper wire is used as cutting tool for removing the work piece material.

- The Distilled water as coolant is used for removing the work piece material because of
  - High cutting speed
  - Wire cooling
  - Brass coated powder is removed

Specimen – Rectangular Block (1st machining process)

1. Diameter of wire : 0.20 mm
2. Type of wire: copper with brass coating wire.
3. Desired shape to be made from rectangular block: Rectangular rod of length 10 mm.

S.No	Parameter	Value
1	Pulse on Time (Ton)	124 spark/sec
2	Pulse off Time (Toff)	56 spark/sec
3	Wire Power (I_p)	230v
4	Wire gap (V_p)	2mm

5	Current	3 amps
6	Water Pressure ($W_{p)}$	1bar
7	Wire Feed (WF)	2mm/min
8	Wire Tension (WT)	7
9	Servo Voltze (SV)	20v
10	Servo Feed (SF)	2100
11	Machining Time	52 min

Specimen – Rectangular Block (2 nd machining process)

1. Diameter of wire : 0.25 mm
2. Type of wire: copper with brass coating wire.
3. Desired shape to be made from rectangular block: Rectangular rod of length 10 mm.

S.No	Parameter	Value
1	Pulse on Time (Ton)	130
2	Pulse off Time (Toff)	56
3	Wire Power (I_p)	230
4	Wire gap (V_p)	2
5	Current	3 amps
6	Water Pressure ($W_{p)}$	1
7	Wire Feed (WF)	2
8	Wire Tension (WT)	7
9	Servo Voltz (SV)	20
10	Servo Feed (SF)	2100
11	Machining Time	32 min

Specimen – Rectangular Block (3 rd machining process)

1. Diameter of wire : 0.25 mm
2. Type of wire: copper with brass coating wire.
3. Desired shape to be made from rectangular block: Rectangular rod of length 10 mm.

S.No	Parameter	Value
1	Pulse on Time (Ton)	131
2	Pulse off Time (Toff)	60
3	Wire Power (I_p)	230
4	Wire gap (V_p)	2
5	Current	5 amps
6	Water Pressure ($W_{p)}$	1
7	Wire Feed (WF)	2
8	Wire Tension (WT)	7
9	Servo Voltze (SV)	20
10	Servo Feed (SF)	2100
11	Machining Time	26 min

VI. RESULTS AND DISCUSSIONS

EDM Output Results:

Table: Machining Time Results

S.NO	1^{st}Machining process in mins	2^{nd}Machining process in mins	3^{rd}Machining process in mins
1	52	26	20

MRR= depth of cut * cross sectional area
Machining time

MATERIAL REMOVAL RATE RESULTS:

S.NO	1^{st}Machining process in mm^3/min	2^{nd}Machining process in mm^3/min	3^{rd} Machining process in mm^3/min
1	12.02	17.08	20.16

% of Tool Wear:

S.N	1st cut piece	2nd cut piece	3rd cut piece
1	4	6	8

SURFACE ROUGHNESS RESULTS:

S.No	1st cut piece	2nd cut piece	3rd cut piece
1	0.022	0.0283	0.0281

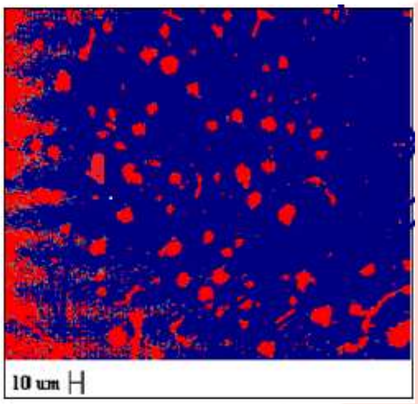
OUT PUT RESULTS:

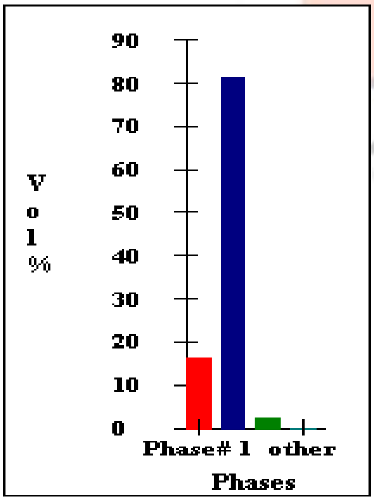
	1st cut piece	2nd cut piece	3rd cut piece
MRR	12.02	17.08	20.16
TOOL WEAR	4	6	8
SURFACE ROUGHNESS	0.022	0.0283	0.0283

Note:
1. Machining time is continosly decreases from specimen 1st cut to 3rd cut
2. The material removal rate is continuosly Inecreases from specimen 1st cut to 3rd cut
3. Tool wear is continuosly increases specimen 1st cut to 3rd cut
4. Surface roughness is continuosly increases 1st cut to 3rd cut

MICROSTRUCTURE COMPARISION

1st Machined piece

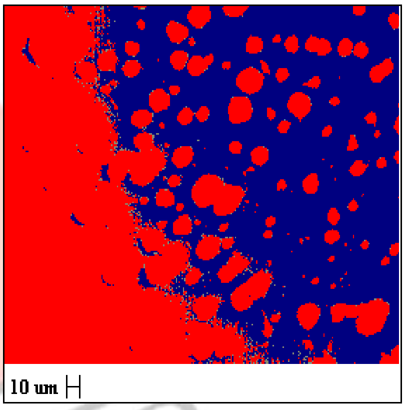


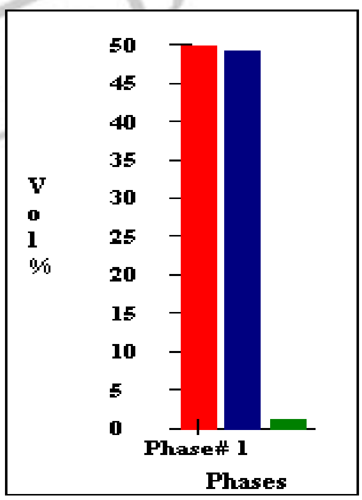


Phase/Volume Fraction analysis :Results Summar

Fields measured	1
Analysed Area	.064 sq mm
Standard used	ASTM E 562

2nd Machined piece





Phase/Volume Fraction analysis :Results Summar

Fields measured	1
Analysed Area	.064 sq mm
Standard used	ASTM E 562

	Phase# 1 %	Phase# 2 %	carbides %	other %
Volume% estimate	16.35	81.45	2.21	.
std dev.	.	.	.	.
95% CI	.	.	.	.
%RA	.	.	.	.

	Phase# 1 %	Phase# 2 %	other %
Volume% estimate	49.83	49.18	99
std dev.	.	.	.
95% CI	.	.	.
%RA	.	.	.

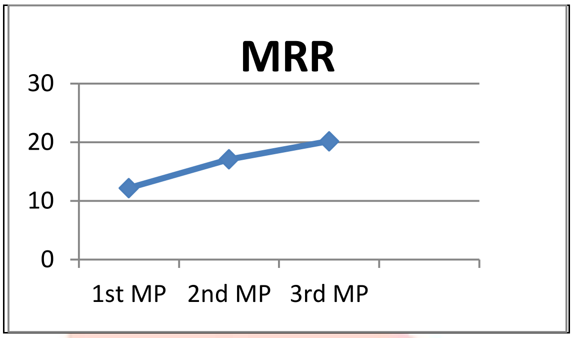
Note :

Graphite Nodules observed in specimen A is small range and specimen B is heavy range in ferrite and pearlite matrix.

PLOTS & DISCUSSIONS:

MATERIAL REMOVAL RATE RESULTS:

S.NO	1st Machining process	2nd Machining process	3rd Machining process
1	12.20	17.08	20.16



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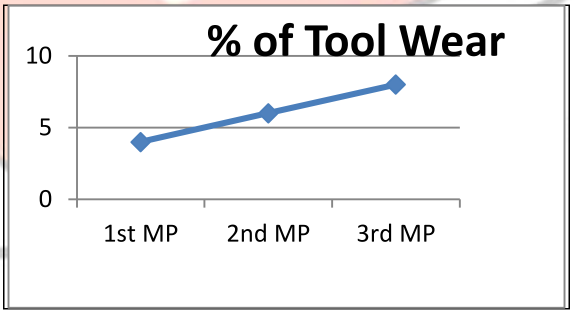
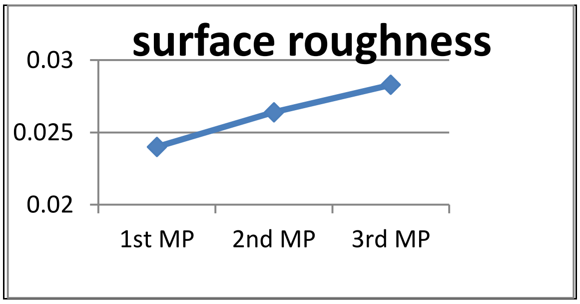
% of Tool Wear:

S.N	1st machined tool	2nd machinned tool	3rd machined tool
1	4	6	8



SURFACE ROUGHNESS RESULTS:

S.No	1st Machining	2nd Machining	3rd Machining
1	0.024	0.0264	0.0283

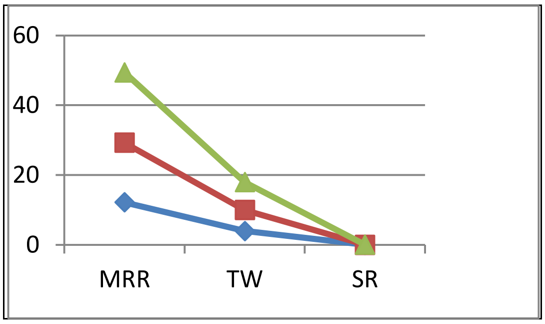


OUT PUT RESULTS:

	1st Machining	2nd Machining	3rd Machining

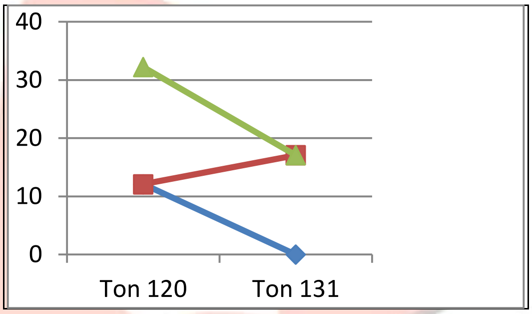
MRR	12.20	17.08	20.16
TOOL WEAR	4	6	8
SURFACE ROUGHNESS	0.024	0.0264	0.0283

Comparison of Output Results :

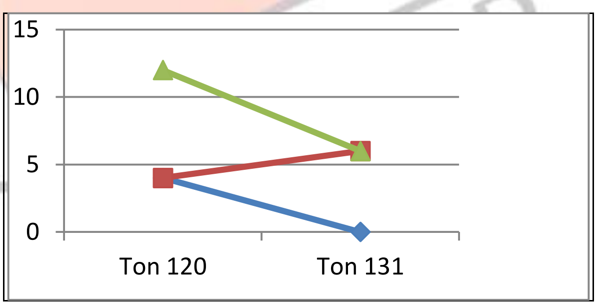


PULSE ON TIME VS MRR

Pulse on time



PULSE ON TIME VS TW:



CHEMICAL COMPOSITION RESULTS:

1st Machining piece- Square of side 10mm and length 23.7mm

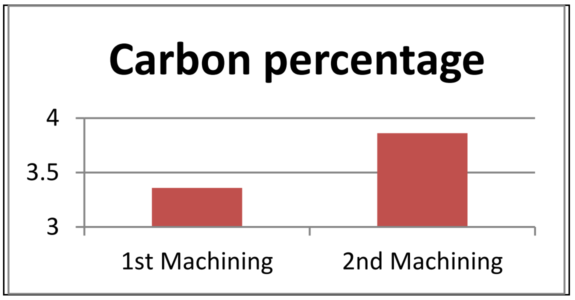
Specimen	C%	MN %	SI %	S %	P %	MG %
1st Machining	3.36	0.28	2.20	0.014	0.023	0.019

2nd Machining piece- Square of side 10mm and length 23.7mm

Specimen	C%	MN %	SI %	S %	P %	MG %
2nd Machining	3.86	0.36	2.65	0.088	0.088	0.091

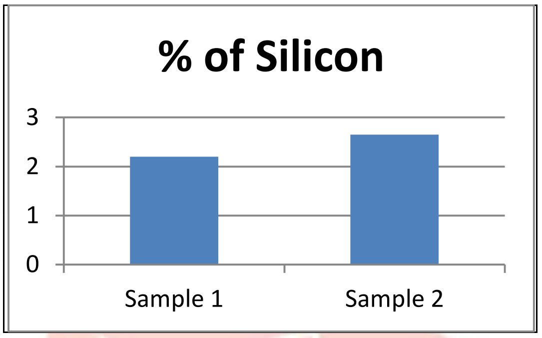
Copper comparison:

S.NO	**Sample**	**% of C**
1	1st machining	3.36
2	2nd machining	3.86



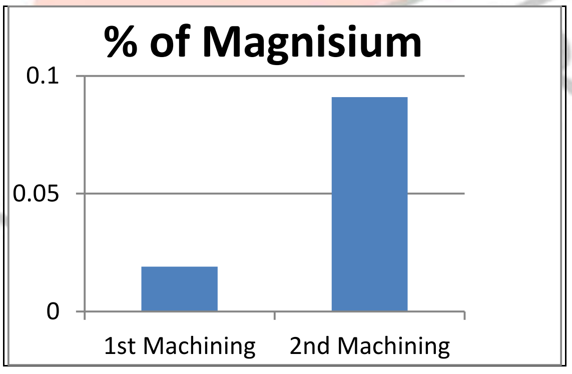
SILICON COMPARISM:

S.NO	**Sample**	**% of Si**
1	1st machining	2.20
2	2nd machining	2.65



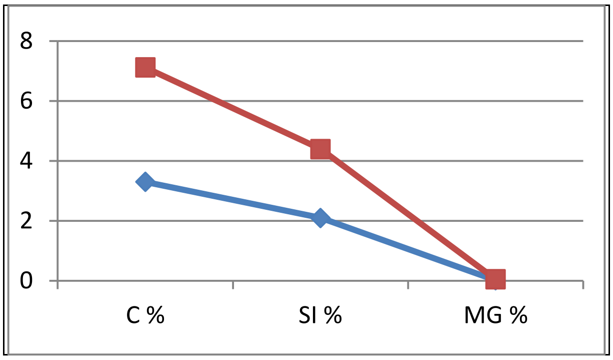
MEGNISIUM COMPARISM:

S.NO	**Sample**	**% of Mg**
1	1st machining	0.019
2	2nd machining	0.091



CHEMICAL COMPOSITION COMPARISION:

S.NO	% of Content	1st Machining	2nd Machining
1	C	3.36	3.86
2	SI	2.20	2.65
3	MG	0.019	0.091



VII. CONCLUSIONS

The two different compositoned SG Cast Iron is used in this project above results are observed conculded as follows

1. Machining time is continuosly decreases from 1st machining to 3rd Machining.
2. Due to increase in Wire Diameter and current Machining time Decreases.
3. The material removal rate is continuosly Inecreases from 1st machining to 3rd Machining.
4. Due to increse of current Material Removal rate increses.
5. Tool wear is continuosly increases from 1st machining to 3rd Machining.
6. Surface roughness is continuosly increases from 1st machining to 3rd Machining.

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