Multi-Objective Optimization in Electro Discharge Machining of Al/Al_2O_3 Metal Matrix Composite

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Certificate of Approval

This is to certify that the thesis entitled ***Multi-Objective Optimization and Electro Discharge Machining of Al/Al_2O_3 Metal Matrix Composite*** submitted by ***Mr. Prashant Pandey*** has been carried out under my supervision in partial fulfillment of the requirements for the Degree of ***Master of Technology*** in ***Production Engineering*** at **National Institute of Technology**, **Rourkela**, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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PRASHANT PANDEY

# Abstract

In recent years, Al/Al_2O_3 metal matrix composites are gaining more attention in manufacturing industries particularly in aerospace and automobile industries due to their excellent mechanical properties. So, it became necessary for manufacturers to study the machining behavior of these composites. Addition of Al_2O_3 as a reinforcing material helps in improving the mechanical properties of composite. In the present research work the Al/Al_2O_3 composite was prepared by powder metallurgy method and then non convention machining process mainly electro discharge machining (EDM) is used for machining of metal matrix composites. In this study, three machining parameters such as pulse duration (T_{on}), discharge current (I_p) and duty cycle (τ) have been taken to assess their influence on material removal rate (MRR), surface roughness (R_a) and tool wear rate (TWR). The study also utilizes the desirability function approach integrated with Taguchi has been used to generate the optimal machining condition.

Key words: *Al/Al_2O_3, EDM, Desirability, Taguchi method.*

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Chapter 1: Introduction

1.1 Composite Material

Composite materials has an significant role in the areas of industrial as well as advance manufacturing, due to increased demands from technology as there is rapid growth and advance activities in aircrafts, aviation and automobile industries. These materials possess low specific gravity that helps in making their properties enhanced particularly in mechanical strength and modulus to various traditional engineering materials such as metals. The term “composite” mainly specify those material systems which consist of a discrete constituent i.e. the reinforcement, diffused in a continuous phase i.e. the matrix, and which derives its unique characteristics from the properties, architecture and geometry of the constituents, and from the properties of the boundaries or interfaces between different constituents. A composite material composes of two or more chemically and/or physically apparent phases.

Composite materials are engineered or naturally appearing materials produced from two or more composing materials having considerably different chemical or physical properties which possess distinct and separate within the finished structure. The constituent elements, mainly comprises of a reinforcing material, fillers, and a composite matrix binder which differ in form or composition on a macro-scale. The constituent elements retain their own characters i.e. they do not fuse completely into one another although they act in concert. Normally, the constituent material exhibit an interface between one another and can be identified physically. Composites having heterogeneous structures accommodate the importance of specific function and design, infused with properties which limit the scope for classification. However, the new varieties of composites are being invented, each with their own specific purpose and characteristics like the particulate, laminar, flake and filled composites. Particles or fibers reinforced in matrix of another material are the most suitable example of day to day composite materials, which are mostly structural. The present study deals with machinability and machining aspects of Metal Matrix Composites (MMCs) focuses on parametric appraisal and multi-objective optimization in relation to machining performance features. The following sections gathers basic knowledge on MMCs. The major advantages of aluminium alloy based metal matrix composites are as follows:

- High strength
- Enhanced stiffness
- Reduced density
- Enhanced high temperature properties
- Thermal expansion coefficient is controlled
- Thermal or heat management
- Enhanced electrical performance.

1.2 Metal matrix composite

In a material composite, when the matrix is alloy or metal, we get a "Metal Matrix Composite (MMC = Metal Matrix Composite). The matrix is mainly a metal, but a pure one. Except some cases, it is generally an alloy. The main difference between Matrix material from the unreinforced matrix are increased strength, , higher service temperature, higher elastic modulus, improved wear resistance, high electrical conductivity and coefficient of thermal expansion is reduced, and low thermal conductivity.

1.3 Matrix material

The matrix material should be chosen carefully depending upon its properties and behavior accordingly with the reinforcement. One of the best materials for matrix is Aluminium because of its unique combination of excellent electrical and mechanical properties of good corrosion resistance high toughness and low density with high conductivity. Moreover, Al is also cheaper than other light metals which include magnesium (Mg). Corrosion resistance property is one of the major advantage of using Al as metal matrix composite which is very essential for using composites in diverse environments.

1.4 Reinforcement

Reinforcement increases the strength, improves stiffness and the temperature resistance ability and helps in lowering the density of MMC. Reinforcements are mainly characterized by their chemical composition, shape, and properties as ingredient material and their volume fraction used in those composite and their distribution in the matrix. Alumina and other oxide particles like SiC_4 etc. have been used as the reinforcing particles as it is found that these particles helps in enhancing the hardness, tensile strength and wear resistance of aluminium metal matrix composites (AMMCs).

1.5 Applications of Metal Matrix Composites

- AMCs are extensively used in braking systems of trains and cars. The potential use of AMCs in automotive applications include valves, crankshafts, gear parts and suspension arms.
- These composites have been targeted for several functional applications including:
    - Core of an electrical conductor.
    - Push rods in automobile.
    - Flywheels which are used in energy storage.
    - Retainer rings are made from composite material for high-speed motors, and
    - Brake calipers.

- MMCs are used to make Longitudinal bracing beam (stringers) for planes to give high dynamic stability.
- Disc brake caliper for passenger cars are made of MMCs.
- Generally the tank armors are manufactured from metal matrix composites, probably steel where reinforcement mainly used is boron nitride. Boron nitride considered to be good reinforcement for steel because it helps in increasing the stiffness and also it does not dissolve in molten steel.
- Cylinder liners in some engines are made from aluminium metal matrix composite.

1.6 Processing of metal matrix composites

There are several techniques for the processing of Metal-matrix composites. Some of these main techniques are explained below:

1.6.1 Liquid-State Processes

- Casting or liquid infiltration involves infiltration of a particulate or fibrous reinforcement preform by a liquid metal.
- Squeeze casting involves pressurizing the liquid metal into a fibrous or particulate preform and then pressure is applied till solidification is complete.

1.6.2 Solid-State Processes

- Diffusion bonding is considered to be the common solid-state processing method for joining of similar or dissimilar metals. Inter-diffusion of atoms which takes place between metallic surfaces, which are in contact at an elevated temperature, results in bonding.
- Deformation processing can also result in increment of density or result in deformation of the composite material.

- Powder processing methods in combination with deformation processing are used to fabricate short fiber or particulate reinforced composites. This typically includes cold pressing and sintering, or hot pressing which are used to fabricate primarily particle- or whisker reinforced MMCs
- Sinter-forging is a low cost method in deformation processing technique. In sinter forging a powder mixture of reinforcement and matrix is cold compacted, sintered, and is forged to nearly full density.

1.7 Advantages of nonconventional machining for MMCs

Metal matrix composites have higher specific strength and stiffness than that of conventional structural materials that are used in automotive industries and aerospace. MMCs generally comprise metals of light weight which are matrix element, and the whiskers, fibers or particles as the reinforcing elements. MMC reinforcement helps in improvement in the material properties which otherwise the metal does not have. Metal Matrix Composites show substantial improvement in stiffness, tensile strength, elastic limit and fatigue strength when compared to matrix material. Besides this they also have adequate thermal fatigue resistance and high creep strength even at high temperature. Conventional machining such as milling, turning, drilling etc. shows ineffectiveness in advanced materials, since it results in excessive tool wear, poor material removal rate, and increased surface roughness. Traditional machining causes serious tool wear due to abrasive behavior of reinforcing Al_2O_3 particles, thereby reducing the life of the tool. In the view of high tool cost and high tool wear of tooling that are experienced with conventional machining, due to matrix-fiber having two phase structure, many difficulties are came upon in machining of composites e.g. fiber splitting and delamination.

Delamination may occur at any time in the life of a laminate for various causes and has various effects. It can highly affect the tensile strength performance depending on the region of delamination. Among the various types of defects that are caused by drilling, delamination is recognized as the most acute. Many researchers in the past years have tried to study the machinability technique of composites using traditional machining procedures and concluded that there is considerable improvement in dimensional and performance characteristics like surface roughness, tolerance and hole quality. However, due to improvements in product designs and advent of new high cost materials, tolerance requirements and rigorous surface finish pose a challenge in machining of composites. Therefore, to meet these challenges many researchers have utilized advance machining methods such as electric discharge machining, electro chemical machining and ultrasonic machining etc. to successfully machine composite materials, fulfilling rigorous dimensional and performance constraints so non-contact material removal process provides an attractive alternative. This will also reduce or minimize noise and dust problem. In addition to this, extensive plastic deformation and subsequent heat generation associated with conventional machining of composites can be minimized to a high extent. Non-conventional machining appears to be promising technique, since in many fields of applications, it offers special and huge advantages including higher machining rate, better precision, control and wide range of material that can easily be machined.

Chapter 2: Literature Review

2.1 Introduction

The main purpose of this chapter is to provide the brief information about the proposed study from an extensive literature survey. From this literature review a planning and understanding of present work has been accomplished. Selection of material, their day-to-day applications, brief information about the processes utilized in fabrication and development of metal matrix composites, recent advancement or improvements in processing and machining, evolution and efficient use of different optimization technique have been surveyed in this chapter. Many researches and investigations have been carried out to analyze the efficient way for fabrication and effective machining of Al/Al_2O_3 reinforced composite.

Literature review:-

2.2 Al/Al_2O_3 composite

Surappa [1] presents an overview of Aluminium matrix composite material systems on aspects which are related to processing, study of microstructure, variation in properties and its applications. The reinforcement in aliuminium matrix composite are mainly in the form of continuous or discontinuous fibres or whisker, in volume fractions which generally range from a few percent to 70%. **Rosso [2]** studied the nature of advanced metal matrix and ceramic matrix composites. The study mainly focusses on the processes involved in the manufacturing of composite, its application in various fields and the future scope of these potential material. To evaluate the behavior of alumina based composites, the process of compacting and sintering which are used in powder metallurgy process, were investigated. Different compacting pressures and hardness evaluation was carried out to verify the properties of the composite material.

Lindroos and Talvitie [3] studied advances which were made in processing, properties and utilization of metal matrix composites is reviewed. Additionally, various other properties such as corrosion resistant of light weight metal matrix composite and wear resistant steel matrix composites are discussed. Reinforcing material mainly used in aluminium matrix composite was continuous fibre which are employed in some special applications which require high stiffness to weight ratio and strength to weight ratio**.** **Dasgupta et al. [4]** has made an attempt to show the effect of scattering SiC in base alloy where the liquid metallurgy route was adopted and studied its effect on different wear modes like sliding, erosion, abrasion, and combinations of wear modes like cavitation erosion, sliding abrasion, erosion abrasion, sliding and the results which were obtained were compared with the base alloy. The extent within which the aluminium metal matrix composite can show the best performance over the base alloy has been discussed. To study the role of various factors which mainly affects the material removal, worn surface, and subsurface and also the study of understanding the mechanism of material removal was carried out. Wear mechanisms which was a dominant factor was suggested and based on the experimental results obtained the possibility of manufacturing wear resistant components from the metal matrix composite was discussed. To satisfy the quality and productivity requirement simultaneously **Dewangan and Prabhkar [5]** have studied the EDM of stainless steel in which the best process environment was determined. Material removal rate (MRR) during the process was considered to be the productivity estimate and the surface roughness (R_a) of the machined surface was considered to be the quality estimate where the main aim is to maximize the material removal rate and minimize the surface roughness. By selecting the optimal parameter setting these two contradicting requirements have been satisfied simultaneously. Desirability Function (DF) analysis integrated with Taguchi method has been utilized to solve the problem.

2.3 Electro discharge machining

Nanimina et al. [6] investigated the effects of EDM on Al606130%Al_2O_3 metal matrix composites. Pulse on time, pulse off time, and peak current, were selected as the machining parameter and performance parameter were mainly tool wear rate and material removal rate. High machining rate was observed when the current and the pulse on time was high. At low pulse on time and low peak current more tool wear was observed. To study the surface modification phenomena **Kumar et al. [7]** emphasized on the potential of EDM process. Experiments were performed on Die sink EDM in which Material removal rate (MRR), tool wear rate (TWR), circularity, overcut, surface roughness (SR) etc. were considered to be the most important performance parameters. Many researchers carried out investigation for enhancing or improving the process performance. To achieve the best process performance it is necessary to make the proper choice of machining parameter. And also to study, and finding how to solve these multi objective optimization problem is still a difficult and challenging job. **Kiyak and Akır [8]** observed that surface roughness of work piece and electrode were mainly affected by pulsed current and pulse on time, and it is observed that surface roughness was increased if the values of these parameters were high. And also the better surface finish was observed if the value of pulse off time was high and the values of current, pulse on time was low. **Chen and Mahdivian [9]** showed that sparks are generated by electrical circuits of several types and of different wave form of current and voltage of its own and observed that the material removal is a function of discharge energy. **Hocheng et al. [10]** studied the correlation between the major machining parameters which are pulse on time and electrical current, and the crater size produced by a single spark for the representative material SiC/Al. The experimental results not only show the predicted proportionality based on heat conduction model, but are also compared with common steels regarding the material removal rate. The SiC particles can interfere the discharges, though the crater size of SiC/Al is larger than steel. Large electrical current and short on time are recommended in order to carry out the EDM process effectively. Based on the observation and knowledge, one can proceed to the study of machinability of metal matrix composite by EDM process for optimal production cycle. **Leão and Pashby [11]** focused their study on the use hydrocarbon oil which can be considered to be one of the alternative to dielectric fluids. In die sink application it is observed that even water based dielectrics may replace oil-based fluids. Gaseous dielectrics such as oxygen may also be the alternative. But these are not commercially viable so further research is required in this field. **Yang et. al. [12]** suggested a multiple attribute decision making (MADM) method, grey relational analysis (GRA), for solving this kind of problem. Two cases, which are facility layout and dispatching rules selection problem, have been examined by data envelopment analysis (DEA), and were also studied using the GRA procedure, in order to demonstrate the use of GRA. In the case of the facility layout problem, 18 alternative layouts and 6 performance attributes were considered. In the case of the problem of selecting dispatching rules, 9 alternatives dispatching rules and 7 performance attributes were considered. For the two cases above, the results of comparisons indicate that GRA is more effective in solving MADM problem. In order to obtain the micro hole of minimum diameter and maximum aspect ratio **Jong et al [13]** attempted to find the optimal machining parameter conditions. The Taguchi method was utilized to find the relations between process characteristics and machining parameter. When the diameter of the electrode was identical it was observed that electrode wear and the entrance and exit clearances had a major effect on the diameter of the micro-hole. The optimal machining parameter was determined using Grey relational analysis among which the input voltage and the capacitance were found to be the most significant.

2.4 Optimization techniques

Raj et al. [14] studied the optimization of electric discharge machining (EDM) process parameters are mainly based on the Taguchi technique. Also the effect of peak current, pulse off time, pulse on time, and Tool lift time on the EDM output responses has been studied. The output responses mainly taken for the investigation are material removal rate (MRR), Tool Wear Rate (TWR) and Surface roughness (SR). The experiments were designed by using Taguchi Design of Experiments, i.e. L9 orthogonal array is used. **Aliakbari and Baseri [15]** studied the rotary EDM and optimal setting of its process parameters. Most publications which are made on the EDM process are mainly focused towards non-rotational tools, but rotation of the tool helps in providing a good flushing in the machining area**. Singh et al. [16**] carried out the EDM of Al/10%SiCp as metal matrix composites utilizing orthogonal array (OA) combined with grey relational analysis. They studied the multi-response optimization of the process parameters which are, metal removal rate (MRR), tool wear rate (TWR), taper (T), radial overcut (ROC), and surface roughness (SR). **Velmurgan et al. [17]** investigated the effect of some important parameters like Pulse on time(T), Current(I), Voltage(V) and Flushing pressure(P), Tool wear rate(TWR), metal removal rate (MRR), as well as surface roughness(SR) in the electro discharge machining of Al6061 metal matrix composites with 10% SiC and 4%graphite particles were reinforced. The least squares technique was used to compute the regression coefficients and Analysis of Variance (ANOVA) technique was utilized to check the importance of the models developed**. Lin and Lin [18]** suggested a different approach for the optimization of the electrical discharge machining (EDM) process with multiple performance characteristics was studied which is based on the orthogonal array with the help of grey relational analysis (GRA). The grey relational analysis gave some grey relational grade which is utilized to solve the EDM process with the multiple performance characteristics. Then determining the optimal machining parameter by the use of grey relational grade as the performance index. **Purohit and Sahu [19]** reported the effect of pulse-on time (T_{on}), pulse current (Ip), and gap voltage (Vg) on metal removal rate (MRR), tool wear rate (TWR) during ECM of Al-alloy reinforced with 20% by wt. SiCp composites in which a three level and three factor full factorial design of experiment was utilized. The EDM process parameters are found to be correlated conflicting in nature. A hybrid optimization technique PCA has been applied to convert the correlated responses into few numbers of uncorrelated and independent principal components and further TOSIS method has been utilized to convert the multi-objective problem into a single equivalent objective. Different researchers have been exploited these techniques for solving different decision making problems in industrial applications. **Chung et al [20]** studied the blind-hole drilling of Al_2O_3/6061Al composite and its optimization, using rotary electrical discharge machining. Taguchi method was applied for experimental design. Based on the results obtained from Taguchi method analysis, several conclusions were drawn. It is found that the process of machining of Al_2O_3/6061Al composite with the help of blind-hole drilling was feasible. **German et al. [21]** investigated the microstructure and mechanical properties of Al-alloy powder containing Mg and Si and also die compaction and sintering response were studied in order to determine the optimum press sinter processing conditions.

2.5 Objective of research:

The above literature review gives the finding that, MMCs have gained more attention than other reinforced composite materials, but still more research is required for effective production of Al/Al_2O_3 MMCs. Hence the present study is carried to meet the requirement of following objectives.

- Processing of Al/Al_2O_3 by powder metallurgy method to achieve desire properties.
- Electro discharge machining on MMC.
- Analysis of experimental result using Desirability integrated with Taguchi method.
- Optimal parameter selection for overall improvement in machining process.

Chapter 3: Experimentation

3.1 Introduction

The most important task was the fabrication of composite material. The uniform distribution of reinforcement and metal matrix is necessary for the fabrication of composite. Our main aim is to achieve the better physical and mechanical properties through proper bonding between reinforcement and metal matrix.

Various routes available for the fabrication of Al based MMCs are thixo forming, spray deposition, casting and powder metallurgy methods. Spray deposition method helps in improving the material and low segregation property of Al based metal matrix composite but this method is found to be costly, difficulty in acquiring the net shape and also the reinforcement quantity is not uniform and hence this method is not widely used. Casting method involved the difficulty like poor interfacial bonding, segregation, reinforcement clustering etc. are observed in casting method. The Powder Metallurgy is most versatile method for the fabrication of the metal matrix composites due to various reasons which include wide range of variation in volume of reinforcement in matrix, short fibre and long fibre form. It also results in high increament in hardness, indirect strength, and compressive strength of composites. This method is carried out at low temperature and hence offer better control of interface kinetics. . This process employs micro-structural control of the phases which is not present in the liquid phase route. The proper bonding between the reinforcement and metal matrix is achieved through the use of powder metallurgy technique. From literature survey it is found that the percent weight of Al_2O_3 affects the property of composite. When the weight percent of Al2O3 is more than 5%, the tensile strength, hardness, compressive strength increases. And when the weight percent is more than 20% the strength, hardness reach to maximum value after that they decrease gradually. So from papers it has been that for automobile and aerospace applications generally 10-15% weight of Al_2O_3 reinforcement is employed to get the best properties.

3.2 Mixing/blending

Proper mixing of the sample is carried out in Ball planetary mill machine (Model-PULVERISETTE5, Make-FRITSCH, Germany). It comprise of three cylindrical container of chrome steel within which 6 balls made up of chrome steel of sizes 10 mm. To achieve the homogeneous distribution of reinforcement in the mixture, the blending machine continues 2 lakh revolutions.

Fig. 3.1: Ball planetary mill machine

3.3 Compaction of sample:-

Compaction of sample is carried out in Cold Uniaxial press machine (Make-SOILLAB, Type-Hydraulic with maximum load: 20 tonnes). For this purpose, a stainless steel die of 25 mm internal diameter was used. To fabricate the green circular test samples of 25 mm outer diameter a load of 18 ton was applied.

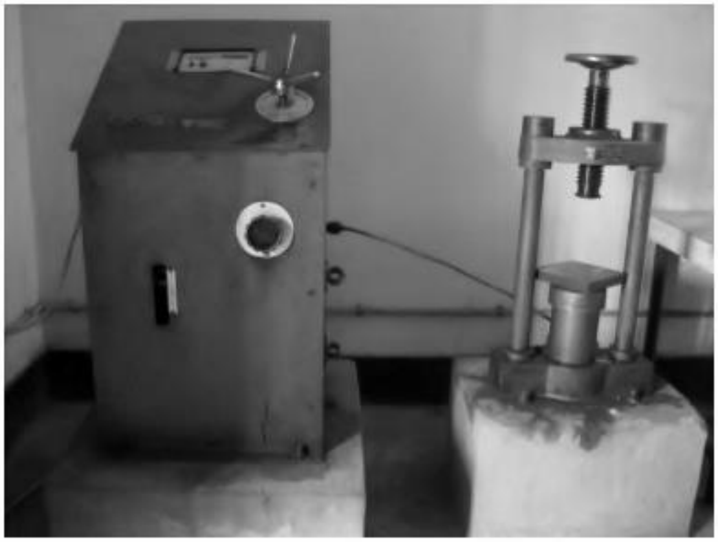

Fig 3.2. Cold Uniaxial press machine

3.4 Sintering

Sintering is carried out in horizontal tubular furnace in the atmosphere of argon and pressure of 1 bar. Nine green samples were sintered at the temperature of 610 ^{0}C just below the melting point of aluminium for holding time of 1 hour. Then furnace is left to cool to room temperature for a time span of 24 hours.

Fig 3.3 Tubular furnace

Specification:-

1. Make-Naskar and Co., Type- Vacuum and Control Atmosphere.
2. Maximum temperature: 1600^0C
3. Cooling rate: 5^0C/min.
4. Controlled atmosphere (vacuum and argon).

After the material is sintered and achieved sufficient strength. The samples are ready to carry out EDM process. The electro discharge machining was carried out in all the nine samples taking into consideration the process parameters that are voltage, current, and duty factor and thereby calculating metal removal rate, tool wear rate, surface roughness. And after getting these results we will be going to perform optimization using Desirability and Taguchi method.

3.5 Density calculation for composite:

The density of the composite is found by following method. First the actual density_then theoretical density is calculated as shown below:-

- Actual density of composite sample:-

$$\rho_c = {M_c}/{V_c} \tag{1}$$

M_c = Mass of composite (4.5 gm)

V_c = Volume of composite

$V_c = (\pi/4)\times d^2 \times t$

d = dia. of sample = 25 mm, t = Thickness of sample = 4mm

After calculation we get ρ_c = 2.290x10^{-3} gm/ mm^3

Theoretical density of composite sample:

$$\rho_c = \frac{1}{\left(\frac{X_{Al}}{\rho_{Al}} + \frac{X_{Al_2O_3}}{\rho_{Al_2O_3}}\right)} \tag{2}$$

ρ_c = Density of composite density (g/mm^3)

X_{Al} = Weight fraction of aluminium (0.9)

ρ_{Al} = Density of aluminium (2.70x10^{-3} gm/ mm^3)

$X_{Al_2O_3}$ = Weight fraction of aluminium oxide (0.1)

$\rho_{Al_2O_3}$ = Density of aluminium oxide (3.95x10^{-3} gm/ mm^3)

After calculation we get ρ_c = 2.780x10^{-3} gm/ mm^3

- Density of tool (Copper)

ρ_{Cu} = 8.96x10^{-3} gm/ mm^3

The actual density comes out to be 2.290x10^{-3} gm/ mm^3 and the theoretical density is found to be 2.780x10^{-3} gm/ mm^3 as calculated using above formula.

3.6 Electro discharge machining

This work mainly focuses to study the effect of major process parameters of EDM on different performance parameters of electro discharge machining (EDM) process. Experiments on samples are carried out in an Electronica Electraplus PS 50ZNC Die Sinking Fuzzy Logic based EDM (specification described in below) as shown in Fig.3.10. A sideways flushing system is employed for efficient cooling purpose and flushing of debris after machining from the electrode gap region. EDM oil (specific gravity = 0.763, freezing point= 94°C) is used as dielectric fluid. The work piece material used is Al, 10%Al2O3 metal matrix composite (MMC). A cylindrical shaped tool made of copper having a diameter of 10 mm is used for machining. Density of copper tool taken having a density 8.96x10^{-3}gm/mm^{3} shown in Fig. 13. Each run of experiment is performed for ten minutes. The tool was taken as anode i.e negative polarity and work piece was taken as cathode i.e positive polarity. The images of the Al, 10%Al2O3 composite after machining are shown in Fig. 3.10.

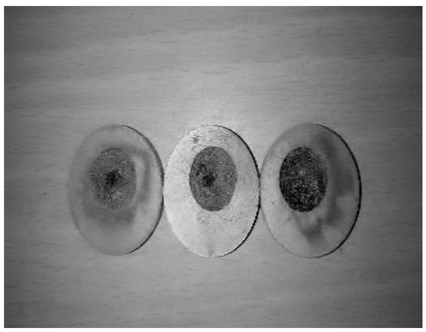

Fig.3.10 Sample after machining

Fig.3.11 Copper tool

3.7 Process Parameters

3.7.1 On time (T_{on})

The machining is mainly done during on time. The spark gap is maintained, current is produced and the work is performed. The longer the spark is maintained more is the rate of material removal and hence the resulting craters produced will be deeper and broader, and hence the surface finish obtained will be rough. It is obvious that if the spark is generated with short duration of time the surface finish obtained will be better. More sparks results in more wear; hence this process is considered to behave quite opposite compared to normal processes in which the tool wear is more during finishing than compared to roughing.

3.7.2 Off time (T_{off})

We know that the machining is mainly done during on time of the pulse, but during the off time there are no pulses and during this period the de-ionization of the die-electric takes place. The debris are removed during the off time, from the machining zone which helps in speed up the operation. It also helps in governing the stability of the process. If the Off time is insufficient it can result in retraction of the advancing servo, erratic cycling and slows down the operation cycle.

3.7.3 Peak Current (I_p)

The peak current is measured on the ammeter during the process. To measure theoretical average current we have to multiply peak current and the duty cycle. Average current indicates the efficiency of machining operation with respect to MRR. Actually work surface may get damage if we use very high current so generally high current is not used. It can also affect the flushing process and also high heat generated can go deep under the work piece which can result in uncontrolled annealing and heat treating process.

3.7.4 Voltage (V)

The voltage used is in the range of 40 to 400 volts and is usually a DC power source. We can also use an AC power source but it is usually combined with a DC rectifier. The preset voltage helps in determining the width of the spark gap between the leading edge of the work piece and electrode. The flushing and machining tends to increase if the voltage setting is high.

3.7.5 Duty factor (τ)

It is one of the most important parameter in the EDM process. Duty factor is given by the ratio of the on time to the total time, as follows:

$$\tau = \left(\frac{T_{on}}{T_{on} + T_{off}} \right) \tag{5}$$

τ = Duty factor

T_{on} =Pulse on time

T_{off} =Pulse off time

The flushing time is very less if the duty factor is high which may lead to short circuit condition and this might lead to the short circuit condition. A small duty factor results in a low machining rate and high off time. Therefore, the optimum value of duty factor must be chosen depending on the the work piece and the tool used and according to the conditions prevailing.

3.7.6 Gap Size

Gap size is the most important parts of the EDM system. The servo control system control the size of the gap whose motion is governed by gap width sensors. It is mainly used to control the movement of the ram head or the quill which helps in controlling the gap size. Gap size varies in the range of 0.010 to 0.050 mm. The feed rate should be equal to the MRR in order to maintain a constant gap size.

3.8 Design of experiment

Dr. Genichi Taguchi of Japan has developed Taguchi method, which helps in reducing the variation around the target in a process with the help of robust design of experiments. Orthogonal Array (OA) developed by Taguchi for designing of experiments mainly to examine how different control parameters affects the mean and variance of a performance characteristic which helps in determining how well the process is running. Orthogonal arrays involves arranging the process parameters factors which affect product quality most by reducing the number of experimentation and the levels at which they should be varies, thereby saving resources and time.

In EDM the performance characteristic is affected by various process parameter. Based on studies and literature survey three machining parameter voltage, pulse on current, duty cycle are selected as control parameters as they are considered to be the most significant parameters in literature review.

Table 3.1. Level of experiment:

Factors	Units	Level 1	Level 2	Level 3
Current (I_p)	[Ampere]	7	8	9
Voltage (V)	[Volt]	60	70	80
Duty factor(τ)		75	100	150

Table 3.2: L_9 Orthogonal Array

Sl. No.	Voltage (V)	Current (Ip)	Duty factor (τ)
1.	7	60	75
2.	7	70	100
3.	7	80	150
4.	8	60	100
5.	8	70	150
6.	8	80	75
7.	9	60	150
8.	9	70	75
9.	9	80	100

Fig. 3.4 Process of Electro discharge machining

Specification:

1. Machine tool: PS50 ZNC
2. Work table dimension: 550×350 mm.
3. Maximum electrode weight: 100kg
4. Maximum job height on table: 250mm
5. Pulse generator: S 50 ZNC
6. Pulse generator type: MOSFET
7. Current range, Ip: 0-50 A
8. Pulse on time range Ton: 0.5-4000 microseconds
9. Duty factor range: 50-93%
10. Open circuit voltage: 40-60V

3.9 Process parameters:

- Current (I_p)
- Voltage (V)
- Duty factor (τ):-

For the given machine $\tau = 5t + 25$

We have taken value of τ that is

$\tau = 75$ for $t = 10$

$\tau = 100$ for $t = 15$

$\tau = 150$ for $t = 25$

3.10 Performance parameters (Output):

- Material Removal Rate (MRR)
- Tool Wear Rate (TWR)
- Surface Roughness (Ra)

3.11 Calculation for performance parameter:

3.11.1 Material Removal Rate (MRR):- MRR is calculated using the loss of volume from the work piece material as cubic millimeter per minute i.e. mm^3/min. The loss in weight is calculated as difference in between the weight of work piece measured before machining and the weight of the work piece measured after machining by an electronic balance weight measuring machine (Sansui (Vibra), Shinko Denshi Co. Ltd. Made in Japan).

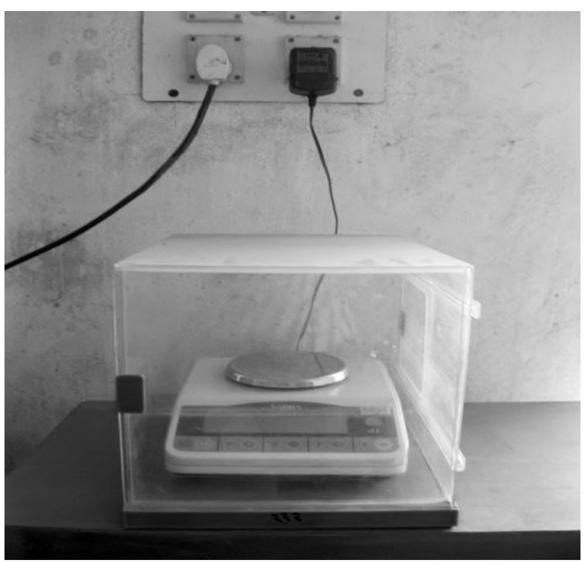

Fig.3.8 Weight Measuring Machine

$$MRR = \left(\frac{W_i - W_f}{\rho_c \times T} \right) \qquad (3)$$

Where, W_i = Work piece initial weight

W_f = Work piece final weight

ρ_c = Density of the composite

T = Time of machining

3.11.2 Tool Wear Rate (TWR):-

TWR is calculated using the loss of volume from the tool material as cubic millimeter per minute i.e. mm^3/min. The loss in weight is calculated by an electronic balance weight measuring machine.

$$TWR = \left(\frac{T_i - T_f}{\rho_t \times T} \right) \qquad (4)$$

Where, T_i = Initial weight of tool

T_f = Final weight of tool

ρ_t = Density of tool

T = Time of machining

3.11.3 Surface roughness: -

The surface profiles of the EDM specimens are measured by using a portable stylus type profile metre like Talysurf (Taylor Hobson). It is based on carrier modulating principle which has stylus which slides over the surface to measure the surface roughness as shown in Fig. 3.9.

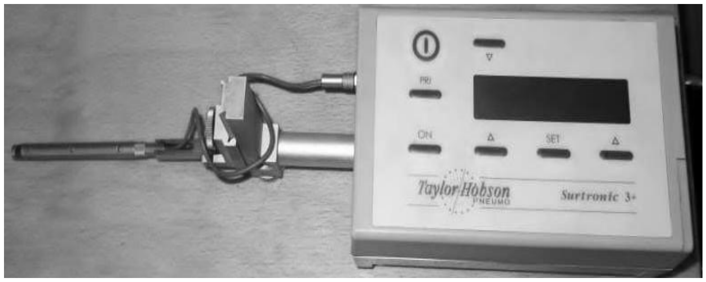

Fig.3.9 Portable Stylus Type Profilometre like Talysurf

Surface roughness can be expressed as, $Ra=\frac{1}{L}\int|y|(x)\ dx\|$, where, L is sampling length, y is profile curve, x is a profile direction. Measurements of surface roughness of EDM surfaces were taken to provide quantitative valuation of the effect of EDM parameters on the surface finish whether it offers better surface finish than other non-conventional machining process.

3.12 Microstructure analysis

The microstructures of samples are studied and examined using a Scanning Electron Microscope (SEM) (JEOL JSM 6480 LV) shown in Figure:-

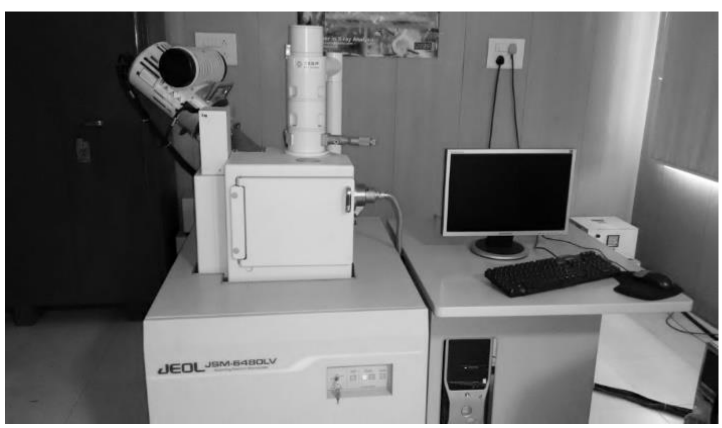

Fig. 3.5 Scanning Electron Microscope

Specifications:

- High-vacuum mode (HV mode)
- Resolution (SEI) :- 3.0 nm guaranteed (Acc V 30kV , WD 8mm)

- Magnification :- 8 x (WD 46mm) to 300,000 x (146 steps, digital indication)
- Image mode :- SEI, BEI (composition image, topographic image and stereoscopic image)
- Probe current: - approximately 1pA to 1µA.
- Low vacuum mode (LV mode)
- Resolution (BEI) :- 4.0 nm guaranteed (Acc V 30kV , WD 5mm)
- Vacuum pressure in the specimen chamber
- Adjustable pressure:- 10 t0 270 Pa
- Lowest pressure :- 1 Pa
- Image mode :- SEI, BEI (composition image, topographic image and stereoscopic image)

Note:-

- SEI: - Secondary electron image
- BEI: - Backscattered electron image
- Acc V: - Accelerating voltage
- WD: - Work distance

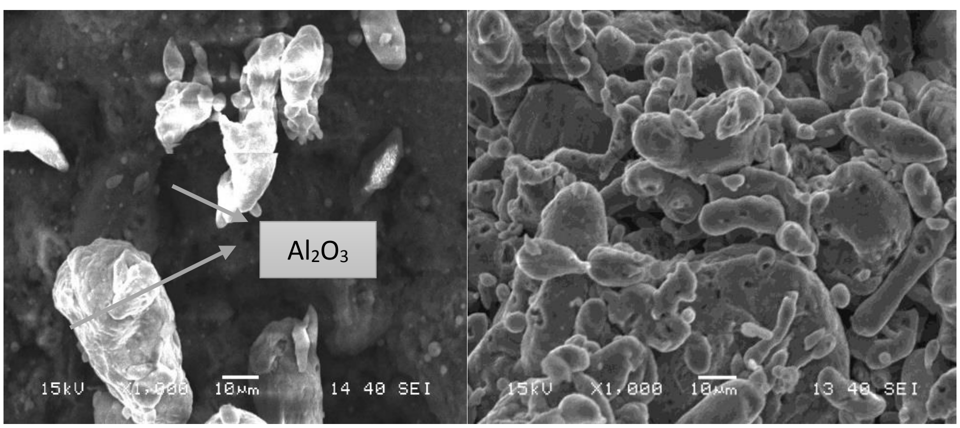

Fig.3.6 Microstructure of Al and Al_2O_3 particles

As shown in the Fig.3.6, we can see the Al and Al_2O_3 particle clearly. The white particles are Al_2O_3 and rest of the particle are Al. the reinforcement which is Al_2O_3 seems to be white because during SEM when electron beam hits the Al_2O_3 particle, being non-conductor of electricity, does not allow electron beam to pass through it as a result the electron particle accumulates all around the reinforced particle and hence appear white, whereas the aluminium being conductor of electricity allows the electron beam to pass through it. We can also see the Al_2O_3 particle are distorted. The reason for distortion of Al_2O_3 particle is the charging of those particle due to accumulation of electrons.

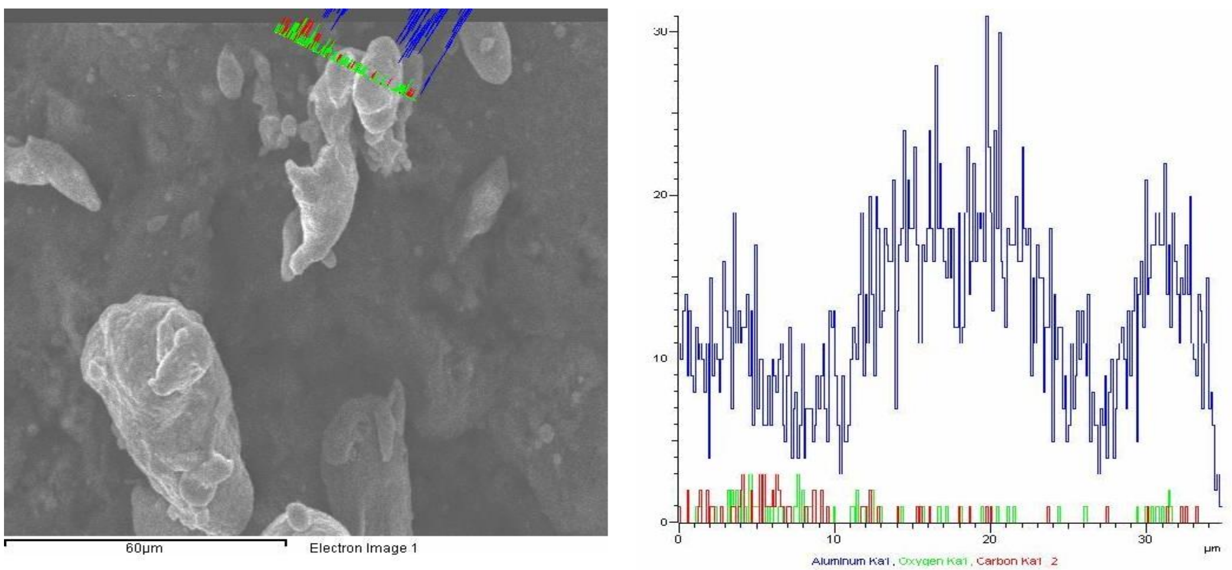

Fig.3.7 Graphical representation of particles

We can see in the graph in Fig. 3.7 Al is present throughout the length, also in the region of Al_2O_3 because since these particle are very close to each other so their rays interfere each other and so the effect is seen throughout. Since the aluminium is oxidized and hence oxygen is present throughout the length.

Chapter 4: Data Analysis

4.1 Desirability Function Analysis

Step 1: We have to determine the individual desirability index (Di), for the corresponding response with the help of the formula given by Derringer et al, In Desirability function there are mainly three types of formula based on response characteristic.

Table 4.1: Experimental data

Sl. No.	MRR (mm^3/min)	TWR (mm^3/min)	R_a (µm)
1.	4.556	0.0669	7.272
2.	3.905	0.0950	6.072
3.	1.6187	0.0550	8.193
4.	1.546	0.0446	7.345
5.	6.1151	0.0223	6.576
6.	3.3453	0.0446	6.027
7.	7.0502	0.0334	8.243
8.	4.7841	0.0233	6.836
9.	8.2733	0.0111	7.671

Table 4.2: Experimental data with higher and lower limit

Sl. No.	MRR	TWR	Ra
Upper limit	8.28	0.096	8.3
Lower Limit	1.55	0.012	6.028

- **Nominal-the-best:** In order to achieve particular target T, value of ỹ is required. The desirability value equals 1 when the value of ỹ equals T. In case ỹ value exceed particular range of target, the desirability value comes out to be 0, and this condition is considered to be the worst case. For nominal-the-best the desirability function is given by

$$Di = \begin{cases} \left(\dfrac{\tilde{y} - y_{min}}{T - y_{min}}\right)^{s} & y_{\min} \le \tilde{y} \le T \\ \left(\dfrac{\tilde{y} - y_{max}}{T - y_{min}}\right)^{t} & T \le \tilde{y} \le y_{\max} \\ 0 & \end{cases} \tag{6}$$

Where, y_{max} represent the upper tolerance limit and y_{min} represent the lower tolerance limits, where s and t represent the weights.

- **Larger-is Better:** In this criteria, the value of ỹ is considered to be the larger the better. When the value of ỹ go beyond a particular range of value, the desirability value become 1; if the ỹ is less than a particular range of value, which is not desired, the desirability value equals to 0. For larger- the better criteria the desirability function is given by

$$Di = \begin{cases} 0 \\ \left(\dfrac{\tilde{y} - y_{\min}}{y_{\max} - y_{\min}}\right)^{r} \\ 1 \end{cases} \quad y_{\min} \le \begin{pmatrix} \tilde{y} \le y_{\min} \\ \tilde{y} \le y_{\max} \end{pmatrix} \tag{7}$$

Where, y_{min} and y_{max} represents the lower tolerance limit and the upper tolerance limit resp. where r represents the weight.

- **Smaller-is-Better**: In this criteria, the value of ỹ is considered to be the smaller the better. When the ỹ is less than a particular range of criteria value, the desirability value becomes equals to 1; if the ỹ go beyond a particular range of criteria value, the desirability comes out to be 0. For smaller-the-better criteria the desirability function is given by

$$Di = \begin{Bmatrix} 0 \\ \left(\dfrac{\tilde{y} - y_{\max}}{y_{\min} - y_{\max}} \right)^r \\ 1 \end{Bmatrix} \qquad y_{\min} \le \begin{pmatrix} \tilde{y} \le y_{\min} \\ \tilde{y} \le y_{\max} \end{pmatrix} \tag{8}$$

Where, y_{min} and y_{max} represents the lower tolerance limit and the upper tolerance limit respectively and r represents the weight. The value of suffix s, t and r used in Esq. 6, 7 and 8 are specified according to the requirement of user and they also represents weight.

In this study, to find out the individual desirability values for surface roughness and tool wear rate "the smaller the better" criteria is applied, and to find out the individual desirability values of material removal rate "the larger the better" criteria is applied.

Table 4.3: Individual Desirability value of Experimental data

Sl. No.	D_1	D_2	D_3	D_o
1	0.447	0.346	0.440	0.409
2	0.351	0.012	0.980	0.160
3	0.012	0.488	0.026	0.053
4	0.001	0.612	0.407	0.061
5	0.679	0.877	0.753	0.766
6	0.268	0.612	1.000	0.547
7	0.818	0.745	0.003	0.124
8	0.481	0.865	0.636	0.642
9	0.999	1.011	0.261	0.641

Step 2: Calculate the overall desirability (D_o). The single desirability index of all the responses can be merged in the form of a single valued called overall desirability (D_o) by using the following equation.

$$D_o = \left(d_1(y_1), d_2(y_2)......d_i(y_i)\right)^{\left(1/k\right)} \quad (9)$$

Where, d_i is the individual desirability of the responses y_i and k denotes number of responses.

Table 4.4: Overall Desirability

I	V	T	D_o	S/N Ratio	P-S/N Ratio
7	60	75	0.408627	-7.77347	2.191027
7	70	100	0.159981	-15.9186	
7	80	150	0.052681	-25.5670	
8	60	100	0.060538	-24.3595	
8	70	150	0.765562	-2.32040	
8	80	75	0.547339	-5.23488	
9	60	150	0.124275	-18.1123	
9	70	75	0.642389	-3.84403	
9	80	100	0.640782	-3.86579	

Step 3: We have to then find the optimal parameter and its level combination. The higher overall desirability value indicates better quality of product. Therefore, on the basis of the overall desirability (D_o), the effect of parameter and the optimum level for individual controllable parameter are calculated.

Step 4: Overall desirability obtained is calculated on MINITAB software, to get the optimal setting as shown in the plot.

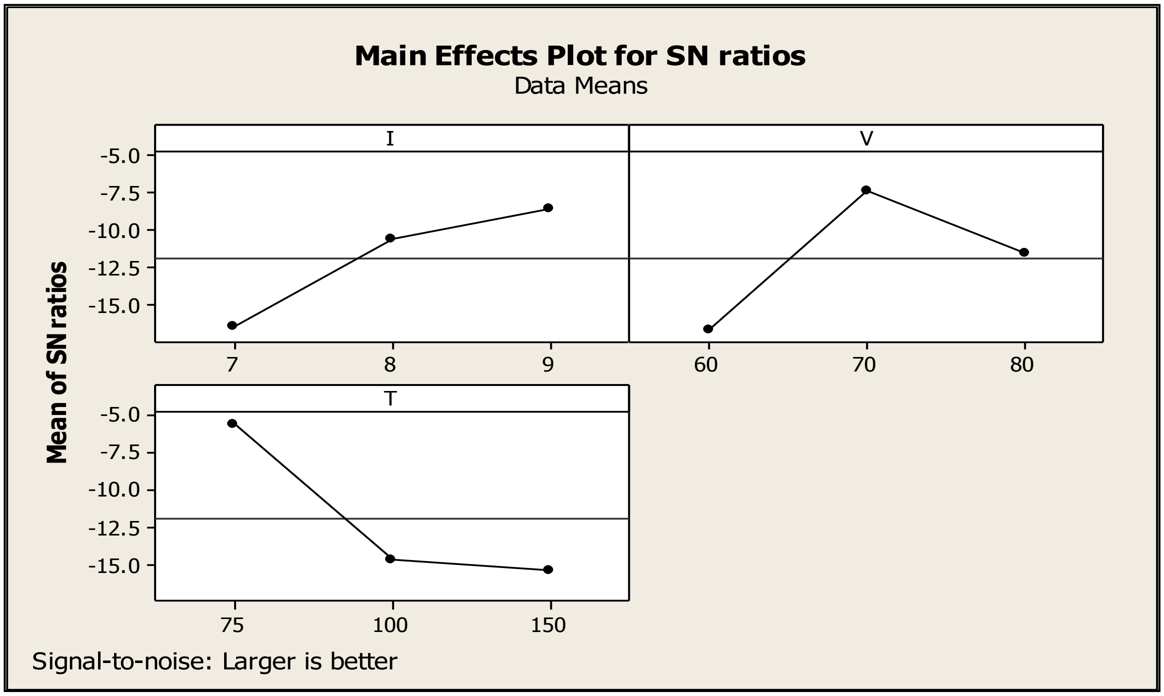

Fig.4.1 Plot for optimal setting of process parameters.

Table 4.5: Optimal process parameter setting

Factors	Voltage	Pulse on current	Duty cycle
Levels	70V	9A	75

The above mentioned optimal setting combination of parameters is obtained through the analysis of S/N ratio plot as mentioned in fig 4.1. The plot is drawn by considering the output responses obtained by Taguchi theory, using MINITAB-16 software.

Chapter 5: Conclusion

Taguchi method is mainly related with the optimization of single response only. Therefore, in this research work a multi-objective optimization technique combining Desirability integrated with Taguchi method is used effectively for optimizing the performance parameters of EDM thereby getting an optimal parameter setting so that machining of advanced materials like Al, 10%Al_2O_3 MMCs can be done. In a production system if we require improvement in product quality and process performance then these integrated approaches can be applied which include multiple response characteristic and can be considered as one of the efficient tool for process improvement and off-line quality control.

<u>Future Scope:</u>

1. The various material properties such as % of Al and Al_2O_3, mesh size of Al and Al_2O_3, sintering temperature etc. can be studied to improve the quality and strength of composites.
2. Apart from EDM other non-conventional machining such as ECM can be also done to study the machinability aspects of Al, 10%Al_2O_3 composites
3. Mathematical model can also develop to optimize the process parameters in order to improve the quality and productivity.

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