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Research Paper

TO STUDY THE OUTPUT PARAMETER OF NON TRADITIONAL MACHINING OF CRYOGENICALLY TREATED WORK PIECE

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This Study about output parameter of Non Traditional machining, i.e., Which are not used conventionally like Electrical Discharge Machining (EDM) is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques, here it is used for cryogenically treated work piece. In simple terms, EDM is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks). Though EDM is criticized for its low productivity; it secures its market demand due to its high accuracy, finishing, ability of machining hard materials and to produce intricate shapes. In this research work, experimental investigations have been made to compare the machining characteristics of three Alloy steel materials, before and after deep cryogenic treatment using EDM. The output parameters for study are material removal rate, tool wear and surface roughness. The results of study suggest that cryogenic treatment has a significant positive effect on the machining characteristics of alloy steels-tool wear decreases and surface finish of the workpiece after machining improves for all three alloy steels. The best improvement in tool wear and surface roughness is reported by High Carbon High Chromium (HCHCr) followed by WC 6 and then by WC 9. At the same time a slight decrease is observed in Material Removal Rate. However, taking into consideration that tool wear and surface finish of the workpiece after machining are more important parameters in EDM, it can be recommended that cryogenically treated Alloy steels can be efficiently machined through EDM.

Keywords: Electrical Discharge Machining (EDM), Cryogenics, Alloy steel

INTRODUCTION

Electrical Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.

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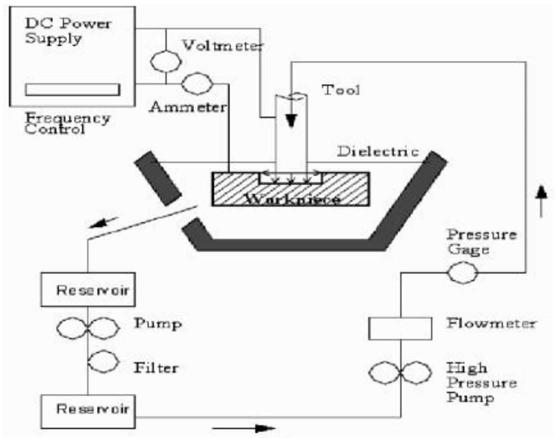
EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive. This method usually employed in production of die cavities via the erosive effect of electrical discharges between a tool electrode and a work-piece (Dauw and Albert, 1992).

In EDM, a potential difference is applied between the tool and workpiece. The tool and the work material are immersed in a diectric medium. Generally kerosene or deionised water is used as the diectric medium. A gap is maintained between the tool and the workpiece.

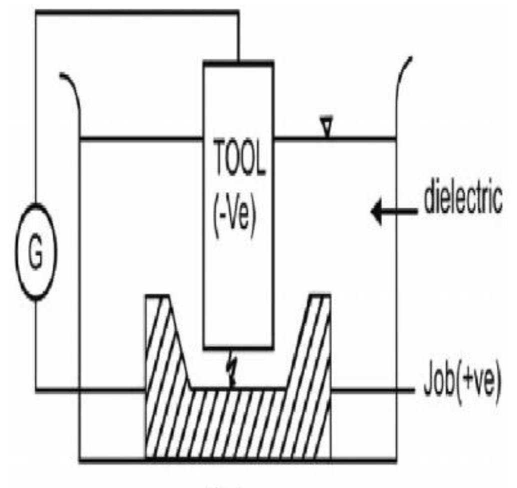
Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. Generally the tool is connected to the negative terminal of the generator and the workpiece is connected to positive terminal.

Figure 1: (a) Schematic of EDM Process (b) Basic Working Principle of EDM Process



(a)

Figure 1 (Cont.)



(b)

As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces. If the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool (assuming it to be connected to the negative terminal). Such emission of electrons are called or termed as cold emission. The "cold emitted" electrons are then accelerated towards the job through the diectric medium. As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and diectric molecules. Such collision may result in ionisation of the diectric molecule depending upon the work function or ionisation energy of the diectric molecule and the energy of the electron. Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions. This cyclic process would increase the concentration of electrons and ions in the diectric medium between the tool and the job at the spark gap. The concentration would be so high that the matter existing in that channel could be characterized as "plasma". The electrical resistance of such plasma channel would be very less. Thus all of a sudden, a large number of electrons will flow from the tool to the job and ions from the job to the tool. This is called avalanche motion of electrons. Such movement of electrons and ions can be visually seen as a spark.

Cryogenics

Cryogenic processing has been traced back to Germany where the Junkers Company used it in aircraft engines built in the late 1930's. It was also used in the early 1940's by a company in Massachusetts on knives. Cryogenic processing is used on racing engines, tooling, brakes, stereo equipment.

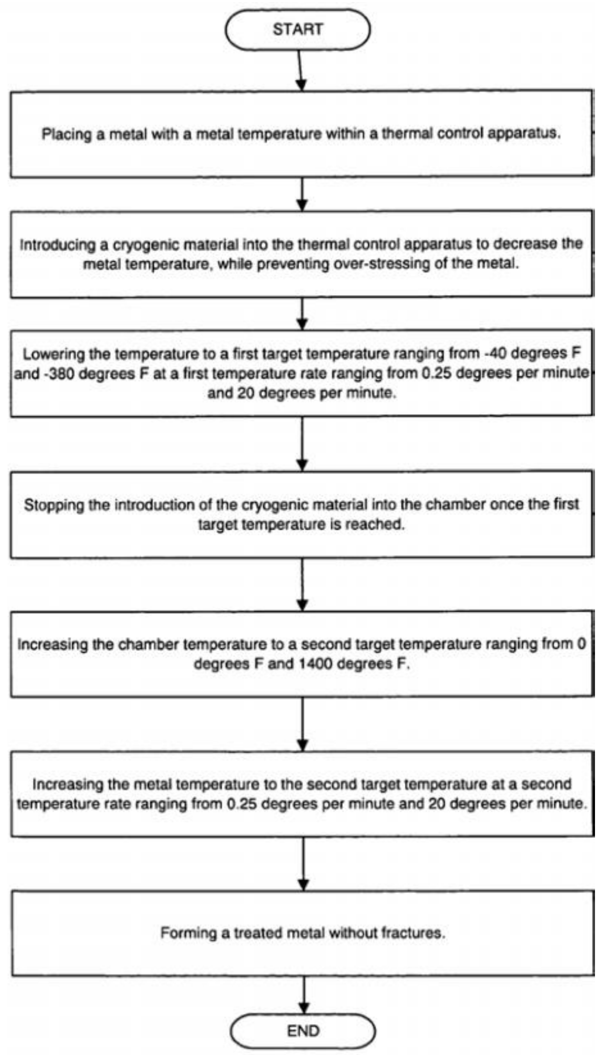
Cryogenic treatment is an extension of the heat-treating process that further enhances metals in the following ways

- Relieves residual stresses.
- Promotes a more uniform micro-structure.
- Precipitates eta-carbides in steels for increased resistance to wear.

Cryogenics as A Process

It is a process that uses cryogenic temperatures to modify materials to enhance their performance. Cryogenic Processing involves the slow reduction in temperature of the material to at least –300 °F (–185 °C) and holding the material at that temperature for some period of hours followed by a slow increase of temperature back to room temperature. In some instances, the material is tempered at elevated temperatures to finish the process. The process is distinct from a process named "cold treating" used by heat treaters to convert retained austenite in hardened steels to a martensitic structure. To represent this process, the flow chart mentioning the intermediate steps is represented in the Figure 2.

Figure 2: Flow Chart Representation of the Cryogenic Processing



LITERATURE REVIEW

Han *et al.* (2006), analyzed the EDM performance and tool wear in copper and alloy-steel system. The large number of process parameters together with the complex interaction of some of the process variables presented a real difficulty in controlling the

EDM output data viz., Material Removal Rate (MRR), tool electrode wear and surface integrity. They discussed the influence of the main electrical parameters and environmental factors such as pulse width, discharge current, polarity, pulse energy and flushing condition on the process performance. Hargrove and Ding (2006), suggested that in EDM operation the work piece as well as the tool (electrode) experience an intense local heating in the vicinity of plasma channel. The high power density would result in the erosion of a part of material both from the work piece and the electrode by the local melting and heating. When high material removal rate is desirable with good surface quality, erosion of electrode is unwanted. So a proper selection of tool materials and choice of parameters like pulse power, width and polarity were investigated.

Kuriakose and Shunmugam (2005), presented the methodology and data from an experiment that measures the normal force and friction force directly in an altered machining setup. The procedure simulates the pure frictional behaviour of the tool-chip interface in cryogenically cutting. The results show that LN2 cooled condition has a significantly lower coefficient of friction than dry conditions in all cases. The data also shows that the friction is lower for Ti-6Al-4V but mixed results obtained for mild steel AISI 1018 when LN2 is applied properly as in the experiment setup as compared to traditional emulsion flooding. Based on the unique pattern of the friction behaviour in the sliding tests, possible lubrication mechanisms using liquid nitrogen are proposed. Huang *et al.* (1999), highlighted, the influence of design factors namely intensity (I), pulse duration (ti), pulse-off time (to) and open circuit voltage (U) to obtain the optimum EDM performance measures of Ti-6Al-4V machining including Material Removal Rate (MRR), Volumetric Electrode Wear Rate (EW) and surface roughness average (Ra). Besides that, the Overall Evaluation Criteria (OEC) which represents all three responses into single index were also proposed. With OEC, complicated evaluation of multi responses can be avoided. Huang and Liao (2003), outlined parametric analysis of the dry EDM process. From the preliminary experiments it was found that EDM with air as the diectric is feasible with reverse polarity. However, high velocity gas flow into the inter-electrode gap through a hollow tubular tool electrode and rotation of the tool are necessary conditions for obtaining a reasonable material removal rate. Flow characteristic of the gas in the inter-electrode gap affected the material removal rate (MRR) and the surface roughness (Ra), as was observed on changing the tool outer diameter and the number of air-flow holes in the tool. Dawei and Jiju (2002), analyzed the different process parameters using Taguchi quality design, ANOVA and F-test to achieve a fine surface finish in wire-EDM and found that the machining voltage, current-limiting resistance, type of pulse-generating circuit and capacitance were identified as the significant parameters affecting the surface roughness in finishing process. Dhar and Chhatopadhaya (2001), optimized the machining parameters using the Taguchi method. The test results were analyzed for the selection of an optimal combination of WEDM parameters for the proper machining of AL/SiC-MMC. Open gap voltage and pulse on period were the most significant and influencing parameters for controlling the metal removal rates. Wire tension and wire feed rate were the most significant and influencing parameters for the surface roughness. Wire tension and spark gap voltage were the most significant parameters for controlling spark gap. Open gap voltage and gap current were the most significant parameters for controlling gap current. Pranshu Bhateja, PEC University of Technology (2011) had done various experimentally investigations on the roll of cryogenically cooling by liquid nitrogen jet on tool wear and product quality in non-cryogenically treated turning of AISI 1040 and E 4340 C steel at industrial speed feed combinations by two types of inserts of different geometry has been done. The encouraging results in clued significant reduction in tool wear rate, dimensional inaccuracy, and surface roughness by cryogenically cooling application mainly through reduction in cutting zone temperature and favourable change in the chip tool and work tool interaction. Dauw and Albert (1992), outlined that cryogenically-processing is the process of cooling the material to extremely low temperature to generate enhanced mechanical and physical properties. Reitz examined the effect of cryogenically-processing on steel and some copper alloys. Research has shown that improvements occur in wear resistant dimensional stability, electrical and thermal conductivity and hardness. The metallurgical aspects include reducing the amount of retained austenite, increasing carbide formation and formation enhancing short-range diffusion. The processing steps are critical. This accounts for the considerable discrepancy in post-treated performance.

PROBLEM FORMULATION

Most components made of hard alloys require high accuracy and complex machining. Therefore, the conventional method in machining of hard alloys is not suitable. Research on machining these using conventional machines mostly highlights chipping, stresses, cutting tool wear and thermal problem during machining which are caused by mechanical energy. Instead of conventional machining, EDM process is a potential machining method to eliminate such problems. This is because there is no mechanical contact between tool and workpiece in EDM system. Furthermore, machining with EDM is burr-less, high accuracy and capable to produce intricate cavities in one operation.

However, not much work has been reported in the investigation of effect of Deep Cryogenic Treated work piece while machining through EDM. In this research work, efforts have been made to study the effect of cryogenically treatment on the performance of EDM machining characteristics using Taguchi design approach to analyze the Material Removal Rate (MRR), Tool Wear (TW) and surface roughness (Ra).

OBJECTIVES OF THE STUDY

The main objectives of the research work are:

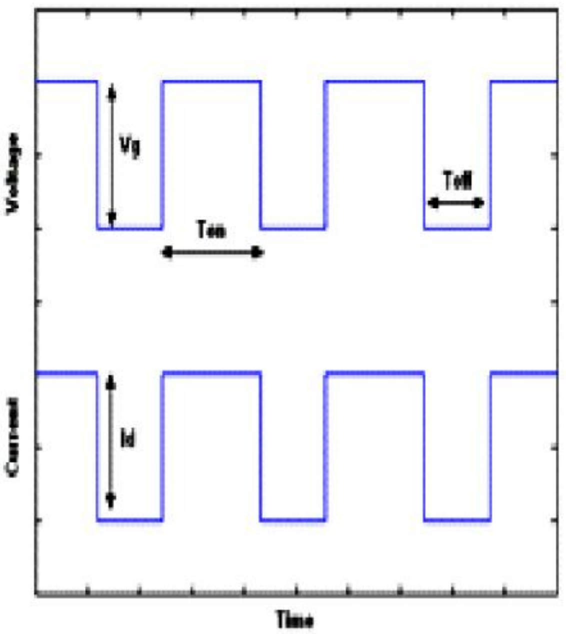
- To study the effect of deep cryogenically treatment on the alloy steels while using EDM.
- Comparison of the machining parameters of three different types of alloy steels, before and after cryogenically treatment.
- Analysis of input machining parameters using Taguchi experimental design technique.

EXPERIMENTAL SET UP

Electrical Discharge Machine (Elektra EMS 5535)

All the experiments have been conducted on a Numerically Controlled (NC) alloy-sinking EDM Machine of Elektra, Electronica Machine Tools India make. In this machine, the Z axis is servo controlled and can be programmed to follow an NC code which is fed through the control panel. The servo control feedback is based on the gap voltage between the tool and the workpiece electrodes. As machining takes place, the tool is fed into the workpiece to maintain a constant gap voltage, and this determines the gap distance. The X and Y axes are manually controlled. All three axes have an accuracy of 5 μm. Through an NC code, machining can be programmed to occur up to a fixed depth of cut. Alternately, sparks can be stopped manually after the desired time interval of machining has elapsed. The power supply system produces a DC pulsed power in the frequency range of 0.22-330 kHz. The pulse can be represented as shown in Figure 3. The pulse has been idealized by considering the pulse delay time as negligibly small. The pulse can be defined in terms of the gap voltage (Vg), discharge current (Id), pulse-on time (T_{on}) and pulse-off time (T_{off}). An additional parameter, duty factor (d) can be represented in terms of the pulse on and off times as:

Figure 3: Idealized Voltage Pulse Generated by the EDM Machine Power Supply and the Corresponding Variation in Current with Time Obtained During Machining



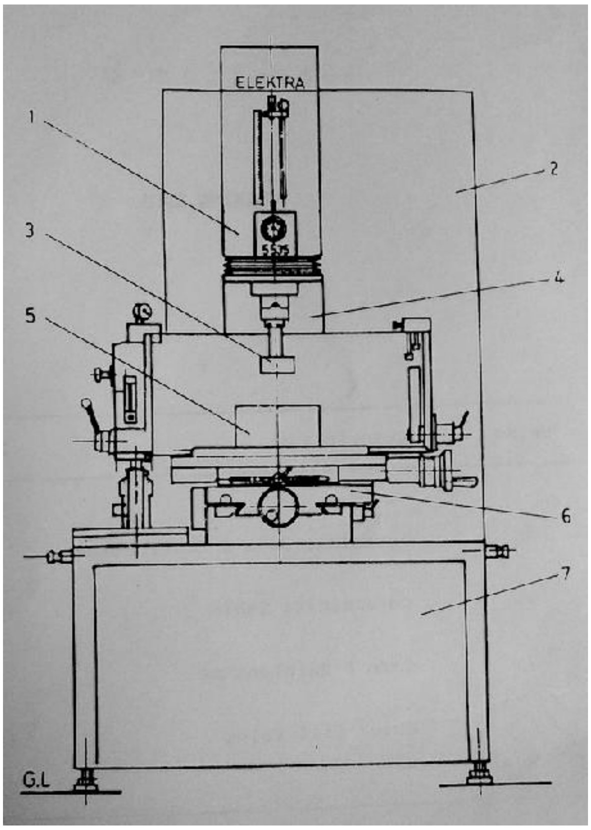
$$d = \frac{T_{on}}{T_{on} + T_{off}}$$

The control panel allows independent control of the gap voltage, discharge current, pulse on time and the duty factor. Corresponding to each Ton value, duty factor can be set to values between 8% and 96% in steps of 8%, subject to the maximum and minimum frequency limitations of the power supply. The duty factor is set by changing the duty factor position (D) on the control panel.

where d = D × 8%

During machining actual (time-average) values of discharge current and gap voltage can be read on the corresponding analogue meters on the control panel. During machining arcing is sensed internally by the control system through an analysis of the current pulse. Power is switched off during a pulse if arcing is sensed. Anti-arc sensitivity determines the average percentage of arcing pulses for which power is switched off. If the anti-arc sensitivity is set to a low value then power is switched off for a higher fraction of arcing pulses.

Figure 4: Schematic Line Diagram of Electric Discharge Machining



Note: 1. Work Head
2. Control Cabinet
3. Electrode
4. Column
5. Work Piece
6. Work Table
7. Base cum Dielectric Unit

Workpiece

The workpiece used in the experiment are 3 types of Alloy Steel (2 samples of each, out of which one is cryogenically treated and other is non-cryogenically treated):

1. High Carbon High Chromium (HCHCr)
2. WC 6
3. WC 9

Tool steels for hot work applications, designated as group Alloy steels in the AISI classification system, have the capacity to resist softening during long or repeated exposures to high temperatures needed to hot work or for alloy-casting other materials. The outstanding characteristics of these tool steels are high toughness and shock resistance.

Electrodes Used

Graphite electrode (12 mm in diameter).

Diectric Used

EDM oil SEO 450

Measuring Instruments

Surfcom: Surfcom model 130 A was used to measure the surface roughness (Ra).

Resolution: 0.001 µm.

TAGUCHI EXPERIMENTAL DESIGN AND ANALYSIS

In the Taguchi method, the results of the experiments are analyzed to achieve one or more of the following objectives:

1. To establish the best or the optimum condition for a product and/or process.
2. To estimate the contribution of the individual variables and their interactions.
3. To estimate the response under the optimum conditions.

Taguchi suggests two different routes to carry out the analysis of the experiments. In first approach, the results of a single run or the average of repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach is for multiple runs where signal to noise ratio (S/N ratio) is used. The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing S/N ratio, the loss associated with a product or process can be minimized. The S/N ratio determines the most robust set of operating conditions from variations within the results. It is treated as a response parameter (transform of raw data).

Taguchi recommends the use of outer array to force the noise variation into the experiment. Generally, the processes are subjected to many noise factors that in combination strongly influence the variation of the response. Most often, it is sufficient to generate repetitions at each experimental condition of the controllable parameters and analyze them using an appropriate S/N ratio.

Signal-to-Noise Ratio

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best and the target lies under acceptable range of product quality are often inadequate. If *Y* is the performance characteristic measured on a continuous scale when ideal or target performance is *T* then according to Taguchi the loss caused *L*(*Y*) can be modelled by a quadratic function as shown in equation

$$L(Y) = K(Y - T^2)$$

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds an average quality characteristic to be « and standard deviation to be ±. Let desired performance be «1 .Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor («o/«).

The factor («^{2}/±^{2}) reflects the ratio of average performance «^{2} (which is the signal) and ±^{2} (the variance of performance) the noise. Maximizing («^{2}/±^{2}) or S/N ratio becomes equivalent to minimizing the loss after adjustment. Finding a correct objective function to maximize in an engineering design problem is very important. Depending upon the type of response, the following types of *S*/*N* ratios are employed in practice:

Higher The Better

If the nominal value for a characteristic *Y* is best then designer should maximize the S/N ratio, i.e.,

$$(S/N)_{HB} = -10 \log(MSD_{HB})$$

where

$$MSD_{HB} = \frac{1}{n}\sum_{j=1}^{n}\frac{1}{y^2}$$

Lower The Better

If the nominal value for characteristic *Y* is best then designer should maximize the *S*/*N* ratio, i.e.,

$$(S/N)_{LB} = -10 \log(MSD_{LB})$$

where

$$MSD_{LB} = \frac{1}{n}\sum_{j=1}^{n} y^2$$

ANOVA (Analysis of Variance)

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate, tool wear and surface roughness. Based on the ANOVA, the relative importance of the machining parameters with respect to material removal rate, tool wear and surface roughness is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data:

1. Within treatment variability
2. Observation to observation variability

So ANOVA helps us to compare variability within experimental data. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the mean squared error of Y about its target *T*. The initial techniques of the analysis of variance were developed by the statistician and geneticist *R A*. Fisher in the 1920s and 1930s, and are sometimes known as Fisher's ANOVA or Fisher's analysis of variance, due to the use of Fisher's F-distribution as part of the test of statistical significance. Various formulas for ANOVA:

Sum of square

$$SS_A = \sum_{i=1}^{K_A}\left(\frac{A^2}{n}\right) - \sum_{i=1}^{N}\left(\frac{y_i^2}{N}\right)$$

Total sum of square deviation

$$SS_T = \sum_{i=1}^{K_A} y_i^2 - \frac{\sum_{i=1}^{N} y_i^2}{N}$$

Experimental error

$$SS_e = SS_T - \sum SS_{factor}$$

Mean of square

$$MS_E = \frac{SS_E}{dof_e}$$

The advantages of design experiments are given below:

- Identification of important decision variables, which control and improve the performance of the product or the process.
- Number of trials is significantly reduced.
- Optimal setting of the parameters can be found out.
- Inference regarding the effect of process parameters on the performance characteristics can be made.

CONCLUSION

The effect of cryogenic treatment can be easily observed in respect of all the three response parameters in each type of alloy steel.

1. This treatment majorly improves the tool wear and surface roughness as compared to material removal rate.
2. The best improvement in Tool Wear (72.22%) is reported by WC 9 followed by HCHCr (47.12%) and then WC 6 (30.07%)
3. The best improvement in surface finish (57.36%) is reported by WC 6 followed by WC 9 (42.40%) and then HCHCr (41.53%).
4. Some increment is also reported in Material Removal Rate (MRR) in all the three types of alloy steels after cryogenic treatment but in case of WC 6, it is comparatively less affected
5. The optimum input parameters also get altered due to cryogenic treatment. It is

observed that for the best value of surface roughness, voltage undergoes a shift to the higher side for HCHCr.

6. Tool wear as well as surface finish of the workpiece after machining are critical parameters in EDM. Since cryogenic treatment has a significant positive effect on both these parameters, it can be recommended that cryogenically treated alloy steels can be efficiently machined through EDM.

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APPENDIX

Nomenclature

Symbols	Description
EDM	Electrical Discharge Machine
MRR	Material Removal Rate
TW	Tool Wear
SR	Surface Roughness
Ra	Surface Roughness Average
A	Duty factor
B	Peak current
C	Voltage
D	Pulse on-time
ANOVA	Analysis of variance
S/N Ratio	Signal-to-noise Ratio
²	Duty Factor
OA	Orthogonal Array
MSD	Mean Square Deviation