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Parametric Analysis on the Effect of Cryogenic Treatment on the Work Piece Material of EDM Process

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Abstract

The demand for materials having higher mechanical properties keeps on increasing because of the continuous ongoing developments in mechanical industry. Cryogenic Treatment is a property enhancement heat treatment process applicable for a significant variety of steels. A remarkable improvement in the properties is observed in the case of tool steel and high speed steels. These steels are quite difficult to machine using conventional machine tools. Electro Discharge Machining (EDM) is widely employed for machining of conductive metals with high hardness. This article presents the work to develop or enhance material properties by cryogenic treatment and then establish the process parameters on EDM. Parametric analysis is carried out for process parameters (current, voltage, duty factor and depth of cut) on Electro Discharge Machining taking cryogenically treated work piece and non treated work piece (EN31) and the effects are compared. The experiments are designed by Design of Experiments technique using Taguchis orthogonal array. The optimized process parameters are established for material removal rate and surface roughness and their percentage contribution is calculated using Analysis of Variance (ANOVA) technique. Regression analysis is performed and empirical relation is formed for material removal rate and surface roughness which are analyzed using MINITAB software. The whole experimental study indicates that cryogenic treatment improves material properties and also enhances the material removal and surface finish.

***Keywords**: Cryogenic Treatment, Electro Discharge Machining (EDM), Design of Experiments (DOE), ANOVA, Taguchis orthogonal array.*

1. Introduction

The basis of Electro Discharge Machining (EDM) was first traced far back in 1770's by English scientist Joseph Priesty who discovered the erosive effect of electrical discharges or sparks [1]. The EDM technique was developed by Lazarenko and Lazarenko of Moscow University in the year 1943. The main advantage of the EDM is that the machining process is independent on the hardness of the work piece material and all the materials can be machined as long as they are conductors like metals, metallic alloys and even some ceramic materials. As the process can machine all the materials that are electrically conductive the extremely harder material can be machined by a material with a relatively less hardness like brass or copper [2].

The word cryogenic is derived from two Greek words "kryos" which means "frost" or freezing and "genic" which means "produce" or generated. The cryogenic temperatures generally refer to temperature below -150^{0}C. Deep sub zero treatment of metals and alloys is a stress relieving technology. In any material as the level of stress increases the density of the defects like vacancies, dislocations. Stacking faults etc. also increase. This tends to the development of cracks and result in failure. Deep subzero treatment uses the principle of third law of thermodynamics that entropy is zero at absolute zero temperature to relieve stresses in the material [3]. Any changes in properties of steels are attributed to the change in microstructure. The following are the possible causes for the property enhancement in the steels.

- Elimination of the retained austenite.
- Transformation of retained austenite to more stable form as tempered martensite matrix.
- Formation of eta carbides.

- Precipitation, nucleation and growth of ultra fine small secondary carbides with high population density.
- Homogenous and well distributed micro structure.

2. Literature review

Electrical discharge machining (EDM) has been widely employed as the standard process for the machining of internal cavities and holes in dies and tools that have been previously hardened. Rajesh Chowdary [1] has conducted machining of EN-31 die steel with different electrode materials copper, brass and graphite using EDM process. He had evaluated the performance of the three electrodes for material removal, surface texture and heat affected zones. They also observed that with increase in discharge energy, the amount of debris particles in the gap became too large which formed electrically conductive path between the tool electrode and the work piece, causing unwanted discharges that are damaging both the electrode surfaces. A K KHANRA [2] has performed EDM studies on reactive sintered FeAl with different process parameters. They have reported a drastic increase in material removal rate(M.R.R) and decrease in surface finish with increase in applied pulse on time intially. G Krishna Mohana Rao [4] has investigated the influence on machining parameters on electric discharge machining of maraging steels. They have concluded that material removal rate and surface roughness increase with increase in current and duty factor and decrease with increase in pulse on time. Hardness value increased as the current value increases from 5-10Amps and then decreased as the current changes from 10-15Amps. Hitesh B Prajapati [5] has performed experimental investigation of performance of different electrode materials in electro discharge machining for material removal rate and surface roughness (S.R). They have reported that brass electrode gives poor material removal rate and better surface finish than the graphite and copper electrodes. The graphite electrode gives the most material removal rate and gives better surface roughness but it gives higher electrode wear ratio. Pushpendra S Bharti [6] has conducted experimental investigation of INCONEL 718 during Die Sinking Electric Discharge Machining. Copper is used as tool electrode. ANOVA results show that discharge current is most influencing parameter on all performance measures. Discharge current and pulse on time are identified as common influencing parameters for material removal rate, surface roughness and tool wear rate.

P.I.Patil [3] has reviewed on the comparision on effects of cryogenic treatment on different types of steel. They have reported that A Joseph Vimal had studied the effect of cryogenic treatment of EN 31 steels at different stages of heat treatment and observed that by the cryogenic treatment the wear can be decreased by a maximum of 75%. Scanning electron microscopy study showed that the improvement in wear resistance and hardness of the material is due to the complete transformation of austenite to martensite along with the precipitation of a higher amount of fine carbides of size less than 0.5 microns during the cryogenic treatment and subsequent tempering. They reported that the complete process of the cryogenic treatment must be in the order of austenitizing, quenching, deep cryogenic treatment and tempering preferably immediate one after one without time delays. P.Baldissera [7] have reported that the improvement in properties like wear resistance and hardness is due to the removal of retained austenite combined with the fine dispersed η-carbides precipitation. Literature is available on the improvement of hardness in EN 353 and EN 36 carburized steels which showed +3.18 and +17% increase in Vickers hardness. The literature reveals that the cryogenic treatment have positive effect on the selected EN 31 steel in increasing hardness and wear resistance. As this class of steel is used in the application of bearings, dies etc. the increment of the properties increase the life of their application.

Y.Yildiz [8] has investigated through the effects of cold and cryogenic treatments on the machinability of beryllium-copper alloy in electro discharge machining. They have reported an increase in electrical conductivity by the cold and cryogenic treatments and also reported an increase in material removal rate of 19% on cold treatment and 20% on cryogenic treatment on average. They have also found important reductions in electrode wear ratio particularly at higher working currents. The surface integrity of cold and cryogenically treated work piece is more stable or they are deteriorated less than the surface integrity of non treated work pieces after EDM process.

3. Experimental procedure

3.1 Experimental Materials:

The materials that are normally used as electrodes in this EDM are copper, graphite, tungsten and brass. In this experimental work graphite is taken as the electrode material which is having good electrical properties. Graphite is expected to give better surface finish and is one of the major commercially available EDM electrodes. The electrode is prepared with a cross section of 15*15 mm^2, and length of 40 mm. A hole of 10 mm is drilled on the top and suitable tapping is done to fix the electrode to the tool holder. The work piece material used for the present work is EN 31 steel which is having a wide range of applications in industrial field like manufacturing, cryogenic, space applications etc. The spectro analysis results for the composition of the work piece are listed as under:

Table 1 Chemical composition of work piece:

Element	C	Si	Mn	P	S	Cr	V
Comp(%wt)	1.08	0.28	0.46	0.024	0.03	1.10	0.006

Table 2. Major properties of the tool and work piece are listed as follows:

Material property	Tool	Work piece
Density	1.81 gm/cc	7.81 gm/cc
Thermal conductivity	80W/m-K	46.6 W/m-K
Electrical resistivity	$3.5*10^{-3}$ ohm-cm	0.0000218 ohm-cm
Specific heat capacity	7.10 J/g-^{0}C	0.475 J/g-^{0}C
Melting point	3350^{0}C	1510^{0}C

3.2 Heat Treatment Process:

The entire heat treatment of the work piece is done in three stages with no time interval between the stages. The heat treatment cycles are as follows:

The first stage of the heat treatment is the hardening of the material by heating the work piece above the re crystallization temperature followed by quenching in salt bath. The hardening makes the material brittle due to the formation of martensite.

The hardening is immediately followed by the deep cryogenic cycle. Literature reveals that the cooling time to the lowest temperature has very little significance, so the cooling has been done slightly faster in order to save the time and cost. Soaking of work piece at 120^{0}C for 30 minutes has been done to prevent any possible cracking. The soaking time which is most important in the property enhancement has been kept constant to 24 hrs. Both the cooling and heating of the work piece is done at the rate of 1^{0}C/min.

The cryogenic cycle is immediately followed by a single tempering cycle at 180^{0}C for 2 hrs. The internal stress generated in the work piece due to formation of martensite gets relieved due to tempering.

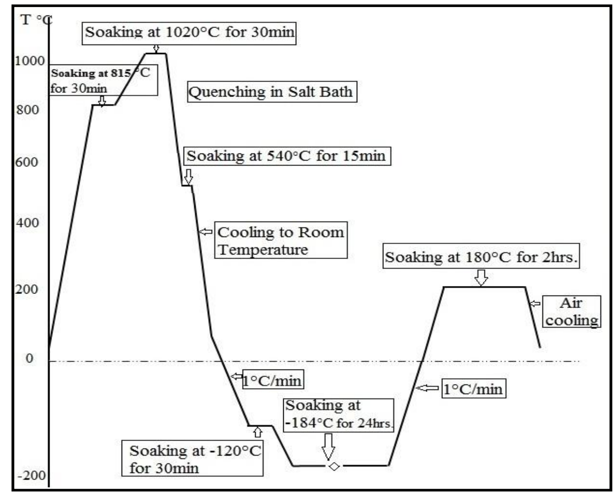

Figure 1. Full heat treatment cycle of work piece material.

3.3 Design of Experiments:

In order to determine the factors and levels of the EDM process some trial experiments have been performed initially. From the results of the trial experiments 4 factors each at 4 levels have been decided for the experimentation and are as follows:

Table 3. Factors and levels decided for the experimentation on EDM

Factor	Levels
Current (A)	10, 15, 20, 25
Voltage (V)	30, 40, 50, 60
Duty factor	30, 40, 50, 60
Depth of cut (mm)	1, 2, 3, 4

For testing these four parameters with all possible settings it takes 4^4 total number of experiments which is not feasible on the grounds of time and cost. The Taguchis method solves this problem by the effective use of the specially designed orthogonal arrays through which the process parameters can be studied with minimum number of experiments. The Taguchi method is applied in four steps as follows:

- Brainstorm the quality characteristics and design parameters that are significant to the product/ process.
- Design and conduct experiments.
- Analyze the results to determine the optimum conditions.

- Run a confirmatory test using the optimum conditions.

The design parameters have been already decided from the trial experiments. Now for the design of experiments for four factors at four levels the taguchis L16 orthogonal array is used.

The machinery used to perform the experiments was a die sinking EDM machine of type SPARKONIX MOS of maximum current of 25A manufactured by SPARKONIX (I) PVT.LTD. The machine is provided with a jet flushing system to ensure the adequate flushing of the debris from the gap zone. The pressure of the dielectric fluid and flushing are adjusted manually at the beginning of the experiment. The dielectric fluid used for the EDM machine is commercially available EDM oil. The variable parameters that can be changed on the machine are current, gap voltage, pulse on time, pulse off time, polarity, feed, speed and lift. The polarity, speed, feed and lift are kept constant throughout the experimental procedure.

For performing the cryogenic treatment the cryogenic processor of type CP220LH is used and one set of the work piece is subjected to hardening, deep cryogenic treatment followed by single temper cycle.

4. Results and Analysis

The entire results of the experiments have been summarized and are listed as below:

4.1 Material Removal Rate:

The results are analyzed by plotting the main effects of the SN ratios of the output responses. If the larger characteristic of 'y' results in improved product/ process performance (material removal rate) then the formula will be:

$$\frac{S}{N}\ (\Theta) = -10\log[\frac{1}{n}\sum_{i=1}^{n} yi^{-2}]$$

4.1.1 Non treated work piece:

From the main effects plot it is interpreted that the material removal rate is increasing as the current increases from 10A to 20A as the trend of the SN ratio is increasing. This is expected as the increase in current produces strong spark, which produces the high temperature, causing more material to melt and erode from the work piece. At the highest level of the current value it showed a decrease in material removal rate with respect to previous level which is due to the higher edge burn off at the higher current value which is causing the tool to retract continuously slowing down the material removal.

The maximum material removal rate is observed at the lower voltage setting of 30V. It showed a slight increase in MRR from 40 to 50V which is negligible so we can interpret that the MRR has been almost constant. Still increasing the gap voltage has reduced the MRR from 50 to 60 V.

Table 4. Material removal rate (gm/min) and surface roughness (µm) of cryogenically treated and non treated work piece

S.No	I(A)	V(V)	D.F	DEPTH (mm)	M.R.R(non cryo)	M.R.R(cryo)	S.R(non cryo)	S.R(cryo)
1	10	30	30	1	0.0179	0.0274	2.68	2.38
2	10	40	40	2	0.0700	0.0708	3.51	3.11
3	10	50	50	3	0.0768	0.0679	4.09	3.64
4	10	60	60	4	0.0244	0.0378	3.60	3.97
5	15	30	40	3	0.1600	0.1606	3.50	3.10
6	15	40	30	4	0.0415	0.0518	3.54	2.78
7	15	50	60	1	0.0583	0.0629	2.96	3.50
8	15	60	50	2	0.0944	0.1093	5.24	4.83
9	20	30	50	4	0.1555	0.1750	5.99	5.98
10	20	40	60	3	0.1181	0.1127	4.88	5.34
11	20	50	30	2	0.0653	0.0686	3.89	3.56
12	20	60	40	1	0.0882	0.1214	4.43	3.54
13	25	30	60	2	0.0833	0.0700	6.35	6.64
14	25	40	50	1	0.0739	0.0739	5.36	5.20
15	25	50	40	4	0.1400	0.1707	4.39	4.03
16	25	60	30	3	0.0430	0.0504	3.37	3.04

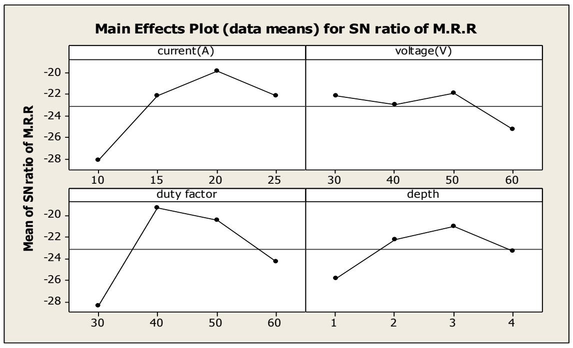

Figure 2. Main effect plots for means of SN ratios of M.R.R of non treated work piece

Duty factor also played important role on material removal rate. The least MRR is observed at low duty factor and the MRR increased rapidly from 30 to 40 and is maximum at 40. Still increase in duty factor from 40 to 60 decreased the material removal rate. This is especially due to very high edge burning at high duty factor along with high currents and the plasma formed between in the gap delays the energy transfer and thus reduces material removal rate. With the increases in depth of cut from 1 to 3 mm the MRR has increased and then decrease from 3 to 4mm. This is due to at starting of the machining it takes some time to stabilize the spark. The increase in depth above 3mm gave every possibility of carbon deposition and the edge burn out hence showed a decrease in MRR.

The optimum parameters for material removal rate are current 20A, voltage 30V, duty factor 40 and depth of cut 3 mm.

Table 5. Analysis of Variance for SN ratios for MRR of non treated work piece:

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
current(A)	3	149.913	149.913	49.971	81.83	0.002	34.42 *
voltage(V)	3	28.179	28.179	9.393	15.38	0.025	6.47
duty factor	3	205.145	205.145	68.382	111.98	0.001	47.10 *
depth of cut(mm)	3	50.446	50.446	16.815	27.54	0.011	11.58
Error	3	1.832	1.832	0.611			0.42
Total	15	435.514					

From the ANOVA the R-Sq value is 99.58% which indicates that the model is predicted to a very high accuracy. The prominent factors that are influencing the material removal rate are duty factor and current.

The regression analysis is performed and the linear regression equation for material removal rate is given by:

M.R.R = 0.0268 + 0.00263 current (A) - 0.00116 voltage (V) + 0.000729 (D.F) + 0.0114 depth of cut (mm).

Confirmatory test is done at the optimum parameters and M.R.R (optimum) = 0.252 gm/min.

4.1.2 Cryogenically treated work piece:

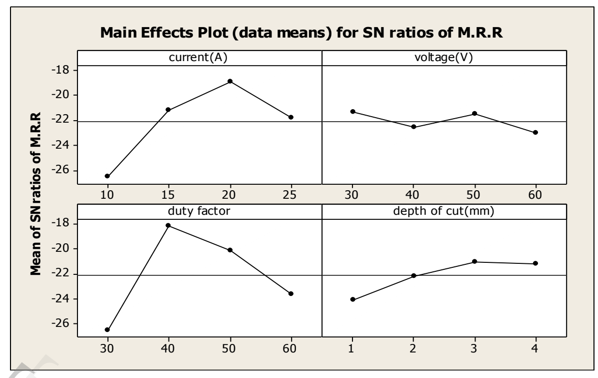

Figure 3. Main effect plots for means of SN ratios for M.R.R of cryogenically treated work piece.

The main effect of the cryogenically treated work piece shows similar pattern for current, voltage and duty factor. For the depth of cut the material removal rate kept on increasing from 1 to 3mm and then stabilized after 3 mm. This shows that for higher depth of cuts the cryogenically treated work piece is giving better results of material removal.

The optimum parameters for material removal rate are current 20A, voltage 30V, duty factor 40 and depth of cut 4 mm.

Table 6. Analysis of Variance for SN ratios for MRR of cryogenically treated work piece.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
current(A)	3	121.886	121.886	40.629	23.46	0.014	37.45 *
voltage(V)	3	7.737	7.737	2.579	1.49	0.376	2.37
duty factor	3	167.306	167.306	55.769	32.20	0.009	51.41 *
depth of cut(mm)	3	23.303	23.303	7.768	4.48	0.125	7.16
Error	3	5.196	5.196	1.732			1.59
Total	15	325.429					

S = 1.31606   R-Sq = 98.40%   R-Sq(adj) = 92.02%

From the ANOVA results the prominent factors that are influencing the material removal rate are duty factor and current. The percentage effect of the current and duty factor also showed a little increase in the case of cryogenically treated work piece.

The regression analysis is performed and the linear regression equation is as follows:

M.R.R = 0.0203 + 0.00288 current (A) - 0.00070 voltage (V) + 0.00040 D.F + 0.0131 depth of cut (mm)

Confirmatory test is done at the optimum parameters and M.R.R (optimum) = 2.8 gm/min.

4.2 Surface Roughness:

The results of surface roughness are analyzed by plotting the main effects of the SN ratios of the output responses. If the diminishing characteristic of 'y' results in improved product/ process performance (surface roughness) then the formula will be:

$$\frac{S}{N}\ ratio = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} yi^2\right]$$

4.2.1 Non treated work piece:

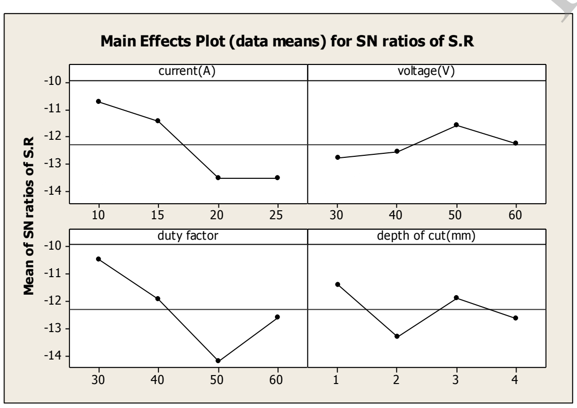

Figure 4. Main effect plot of means of SN ratios of S.R of non treated work piece

For the smaller is the best approach the increasing trend of the SN ratio indicates the decrease in surface roughness. From the main effect plot it is observed that the current and the surface roughness showed an inverse relation at all levels. It is also observed that the increase in the surface roughness is particularly high in between the 15 to 20A. The best surface finish is obtained at the lower currents. This is natural as the high currents create strong pulse and result in vigorous melting of the work piece damaging the surface finish.

The surface roughness is very high at 30V and it kept on decreasing from 30 to 50V. The best surface finish is obtained at 50V. From 50V to 60V the surface finish showed an increasing pattern. The effect of voltage is still quite low on the surface finish.

The duty factor played an important role in the surface roughness and the surface roughness is least at low duty factor of 30. The surface roughness increased as the duty factor is increase from 30 to 50. At the duty factor of 60 it showed a decrease in the surface roughness. This is because of the high pulse on times causing the surface melting uneven accompanied by higher currents.

The plot of the surface roughness with respect to the depth of cut is scattered all over the mean line without any relation. From this we can interpret that the depth of cut has no influence on the surface roughness.

The optimum parameters for surface roughness are current 10A, voltage 50V, duty factor 40 and depth of cut has no effect.

Table 7. Analysis of Variance for SN ratios for MRR of non treated work piece:

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
current (A)	3	24.855	24.855	8.285	5.76	0.092	35.81 *
voltage(V)	3	3.207	3.207	1.069	0.74	0.593	4.61
duty factor	3	28.556	28.556	9.519	6.62	0.077	41.14 *
depth of cut(mm)	3	8.443	8.443	2.814	1.96	0.298	12.16
Error	3	4.314	4.314	1.438			6.21
Total	15	69.395					

S = 1.19913   R-Sq = 93.78%   R-Sq(adj) = 68.91%

From the ANOVA the prominent factors that are influencing surface roughness are duty factor and current.

The regression analysis is performed and the linear regression equation is as follows:

S.R = 1.08 + 0.104 current (A) - 0.0190voltage (V) + 0.0445 D.F + 0.078 depth of cut (mm)

Confirmatory test is done at the optimum parameters and S.R (optimum) =2.45µm.

4.2.2 Cryogenically treated work piece:

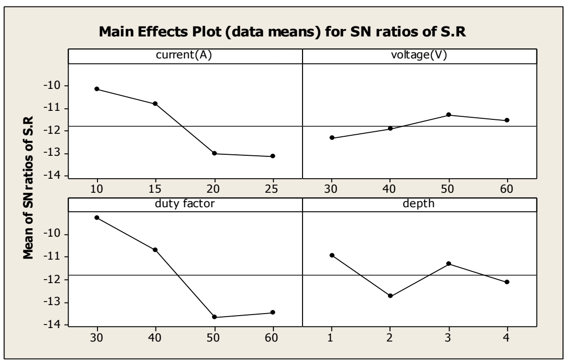

Figure 5. Main effect plots of means of SN ratios of S.R of cryogenically treated work piece.

The main effect plot for the cryogenically treated work piece is similar to the non treated work piece. So the optimized parameters are same for both the cases.

Table 8 Analysis of Variance for SN ratios for MRR of cryogenically treated work piece.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
current(A)	3	27.9033	27.9033	27.9033	51.54	0.004	29.48 *
voltage(V)	3	2.3496	2.3496	2.3496	4.34	0.130	2.48
duty factor	3	55.8860	55.8860	55.8860	103.23	0.002	59.05 *
depth of cut(mm)	3	7.9558	7.9558	7.9558	14.70	0.027	8.40
Error	3	0.5414	0.5414	0.2414			0.57
Total	15	94.6361					

S = 0.424806 R-Sq = 99.43% R-Sq(adj) = 97.14%

From the ANOVA the prominent factors that are influencing surface roughness are duty factor and current.

The regression analysis is performed and the linear regression equation is as follows:

S.R = - 0.21 + 0.108 current (A) - 0.0247 voltage (V) + 0.0724 duty factor + 0.085 depth of cut.

Confirmatory test is done at the optimum parameters and S.R (optimum) =2.22µm.

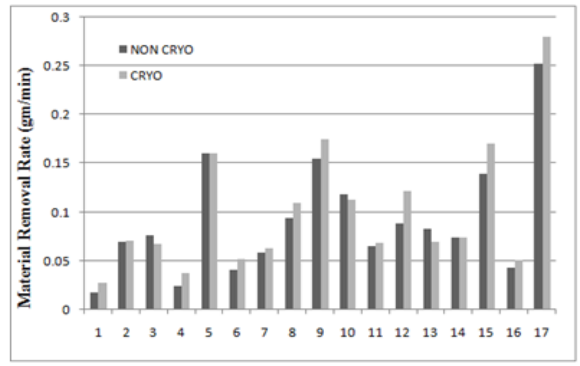

Figure 6. Comparision of M.R.R between cryogenically treated and non treated work piece.

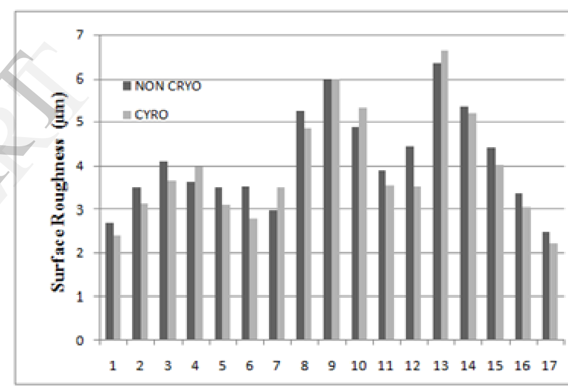

Figure 7. Comparision of S.R between cryogenically treated and non treated work piece.

5. Conclusions

- The optimized parameters for the EDM process for the graphite electrode and both the work pieces in common for M.R.R are current 20A, voltage 30V, duty factor 40, and for surface roughness are current 10A, voltage 50V and duty factor 30.
- Significant increase in M.R.R and Surface finish has been observed on cryogenically treated work piece at most of the levels.
- The results show increase in material removal in cryogenically treated work piece at higher depth of cut which makes it suitable for deeper holes.

- The ANOVA results show that the current and duty factor plays prominent role in M.R.R and S.R for both the work pieces.
- The confirmatory tests are found in good agreement with the results from main effect plots.

6. References

[1] Rajesh Chowdary, H kumar, RK Garg, "*Analysis and evaluation of heat affected zones in electric discharge machining of EN-31 die steel*", Indian Journal of Engineering and Material sciences, 2010, pp 91-98.

[2] A KHANRA, S PATRA and M M GODKNINDI, "*Electrical discharge machining studies on reactive sintered FeAl"*, Indian Academy of Sciences, 2006, pp 277-280.

[3] P.I.Patil, R.G.Tated. *"Comparision of effects cryogenic treatment on different types of steels: A Review"*, pp 1-22.

[4] G Krishna Mohana Rao, S.Satyanarayana, M Praveen, *"Influence of machining parameters on electric discharge machining of managing steels-An experimental investigation"*, proceedings of the world congress on engineering, 2008, pp 978-988.

[5] Hitesh B Prajapati, V.A.Patel, Hiren R Prajapati, *"Experimental investigation of performance of different electrode materials in electro discharge machining for material removal rate and surface roughness"*, International Journal of engineering and applications, 2012, pp 3072-3076.

[6] Puspendra S Bharti, S.Maheshwari, C.Sharma, *"Experimental investigation on Inconel 718 during die sinking electric discharge machining"*, International journal of engineering science and technology, 2010, pp 6464-6473.

[7] P.Baldissera and C.Delprete. *"Deep cryogenic treatment: A Bibliographic Review"*, The open mechanical engineering journal, 2008, pp 1-11.

[8] Y.Yildiz, M.M.Sundaram, K.P.Rajurkar, M.Nalbant, *"The effects of cold and cryogenic treatments on machinability of Beryllium- copper alloy in Electro discharge machining"*, pp 1-6.