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Influence of Cryogenically Treated Cupro-Nickel Electrode on Electric Discharge Machining of Inconel 718 Super Alloy: A Review

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Abstract: ***This review describes a study on the cooling effect on cupronickel electrode while electric discharge machining of Nickel based super alloy Inconel 718 workpiece. To evaluate the influence of cryogenic treatment on material removal rate (MRR), electrode wear rate (EWR) and average surface roughness values (SR) were the three responses observed. Peak current, pulse on time, voltage gap and duty cycle were the controllable process parameters.***
Keywords: Electrical discharge machining, Cryogenic treatment, Inconel 718 super alloy

I. INTRODUCTION

As Inconel 718 is nickel based super alloys find diversified range of applications in aerospace, automobile, chemical plant, power generation, oil and gas extraction, surgical instruments and other major industries [17]. However, it is difficult to machine these alloys with conventional machining processes due to high temperature generation at tool tip resulting in change in mechanical properties of both the tool and work piece. Therefore, non-conventional machining processes like electrical discharge machining (EDM) is normally recommended for the purpose.

In EDM, there is no mechanical contact between the tool and work piece; yet small volume of material is repeatedly removed from both the electrodes through a series of spark discharges. The electrical energy induced by electric sparks is converted into thermal energy resulting in high temperature which melts and evaporates work piece and tool electrode. The molten material in the form of debris is flown away by continuous dielectric flow.

The material removal, surface quality and dimensional accuracy of the machined surface on the work material are related to the amount of spark energy used to erode material during machining. Increase in spark energy definitely improves the material removal but creates numerous adverse effect such as increasing cracks, pores, heat affected zones (HAZ) and inducing residual stresses on the machined surface.

Owing to the complex nature of the process involving the physics of series of spark discharges, it is difficult to observe the process experimentally and necessitates suitable parametric setting to improve the machining efficiency. Thus, low machining efficiency, poor surface finish and dimensional accuracy of the machined surface are the major concerns for tool engineers working on EDM

In recent times, cryogenic treatment has been successfully applied to non-convention machining processes resulting in fruitful application in EDM and wire EDM through treatment of electrodes and wires which are used for machining of toughened and low conductive materials [7].

Cryogenic treatment brings some remarkable improvements to the mechanical properties like increasing the wear resistance, thermal conductivity, hardness and refining the microstructure of the material [10].

These results in effective heat transfer away from the electrodes and in turn improve the wear resistance property and improved machining characteristics of the EDM process.

In view of this, present work has been undertaken to compare the machining efficiency of different cupronickel cryogenic treated (-196 ^{o}C) work-tool pair Inconel 718 super alloy and nickel electrodes with an objective to enhance the machining performance of and to fulfil the minimum surface roughness. Hence, commercially available Inconel 718 and nickel, electrodes were used as the work piece and tool material respectively owing to their poor thermal and electrical conductivities. The objective is to make both the materials suitable for industrial application by enhancing their mechanical properties and analyzing the machining efficiency of different work-tool pair through cryogenic treatment.

The machining efficiency of the process has been evaluated in terms of material removal rate (MRR), electrode wear ratio (EWR) and surface roughness (SR) which are function of process parameters viz., peak current (Ip), pulse-on-time (Ton), duty cycle (τ), gap voltage (Vg).

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II. REVIEW ON CRYOGENIC TREATMENT

Traditionally, the selection of the most favourable process parameters were based on experience or handbook values, which often produces inconsistent machining performance. However, the optimization of parameters relies on process analysis to identify the effect of process parameters on achieving the desired machining characteristics. To determine the optimal machining conditions researchers have adopted various methodologies and strategies. Each approach has got its advantages and disadvantages which have helped both the researchers and practitioners by providing compact yet adequate information so as to select the best one that suits their needs and specific requirements. Since, EDM is a complex machining process, in order to achieve the economic objective of this process, optimal cutting conditions have to be determined.

Rahul et.al shows analysis of surface integrity and metallurgical characteristics of the machined Inconel825 work surface has been carried out in relation to Electrical Discharge Machining (EDM) using Cryogenically Treated Tool (CTT) in comparison with Non Treated Tool (NTT). Degree of severity of surface cracking as well as formation of white layer onto the EDMed Inconel 825 work surface has been investigated herein. The process physics of EDM using CTT has been explained with scientific relevance to EDAX, XRD, residual stress as well as micro-hardness test data of the test samples. For a constant set-ting of process parameters [Peak current (IP) = 10A; Pulse-on time (Ton) = 100 μs; Duty factor (τ) = 85%],surface crack density has been found relatively less (~73%) for the EDMed Inconel 825 work surface obtained by using CTT, as compared to the case of NTT. However, relatively thick white layer (~26%) has been attributed to the EDMed Inconel 825 specimen obtained by using CTT, as compared to the case of NTT (for a common parameters setting: IP= 6A; Ton= 300 μs; τ =85%). Additionally, effects of cryogenic treatment of tool electrode have also been discussed emphasizing aspects of tool life, extent of carbon deposition at the bottom and edge of the electrode, and tool shape retention capability. As compared to NTT, carbon (possibly carbide) layer (deposited at the edge of the tool electrode) of relatively low thickness value (~75%) has been observed for CTT [1].

R. Manivanam et.al productivity and surface quality would significantly affect the performance of micro electrical discharge machining process (μEDM). Thus the machining performance would be enhanced by improving the material removal rate and surface quality. In this investigation, cryogenic LN2 cooling was introduced to the conventional μEDM setup for developing an innovative process of cryogenically cooled μEDM process (CμEDM). The favourable outcomes of this process were estimated by selecting discharge current (Ip) and pulse on duration (Ton) for determining the effects of the machining performance includes material removal rate (MRR) and surface integrity. Surface quality was also analysed by micro structural analysis and a scanning electron microscope (SEM) for evaluation of the effects cryogenically cooled μEDM process. The experimental result shows 54 to 62% of improvement in material removal rate and 22 to 36% in average roughness values. Hence it is suggested that cryogenically cooled μEDM facilitates improvement in productivity and surface quality [2].

Mr. Rachin Goyal et.al the performance of cryogenically assisted electric discharge machining (CEDM) process has been evaluated in the presented research paper. The machining of cryogenically treated (CT) and cryogenically untreated (CUT) AISI D2 tool steel work specimens using cryogenically cooled (CC), CT and CUT copper electrodes have been performed. The effects of various parameters namely, workpiece condition, tool condition, nozzle flushing, peak current, duty cycle, pulse duration and gap voltage have been studied on the performance indicators, viz. the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The best parametric combinations have been suggested to obtain the desired quality characteristics. The interaction effects amongst various parameters have also been presented. An increase of approximately 18% in MRR, a reduction of 26% and 11% in TWR and SR, respectively, were observed, during the machining through CEDM in contrast to EDM. The confirmatory experiments suggested that experimental values were in permissible agreement with the predicted values for all the performance measures. Finally, the comparison of the CEDM with that of EDM process, in the light of SEM graphs has been presented [3].

Sanjeev Kumar et.al in the present work, Ti-5Al-2.5Sn alloy was machined by EDM Process with different machining conditions to investigate their effects on TWR. Moreover, WCT and DCT copper-tungsten electrode were used to study their effects on TWR .Peak current was observed to be most significant process parameter that badly affected the TWR. Cryogenic treatment of electrode material, pulse-on-time and flushing pressure also observed the significant factor. Insignificant effect of pulse-off-time was noticed on the TWR. By comparing the TWR of WCT electrode and DCT electrode, a total improvement of 15.86% was observed in case of DCT electrode than WCT electrode. This improvement is because of their finement of grain particles in case of DCT electrode as compared to untreated electrode. As the temperature is reduced during cryogenic treatment, thermal vibration of atoms become weak resulting in easy movement of electrons in a metal which increases the electrical conductivity of electrode. This reduces the bulk electrical heating of metal. This leads to quick removal of heat from the surface of electrode there by reducing the TWR [4].

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Anil Kumar et.al the present experimental investigations have been carried to evaluate machining efficiency with additive powder mixed in dielectric fluid of electrical discharge machining on Inconel 718 with copper and cryogenically treated copper electrodes. Experiments have been conducted to study the effect of input parameters viz. polarity, type of electrode, peak current, pulse on time, duty cycle, gap voltage, retract distance, and concentration of fine graphite powder on machining efficiency. Machining efficiency is evaluated in terms of tool wear rate (TWR) and wear ratio (WR). The optimum factor/level combination of process parameters has been determined by Taguchi's approach treating performance measure as single objective response. Analysis of variance (ANOVA) is employed to indicate the level of significance of machining parameters for TWR and WR. The recommended optimal process input conditions have been verified by conducting confirmation experiments and significant improvement in TWR and WR is observed [5].

Vineet Srivastava et.al this article describes a study on the cooling effect on copper electrode while electrical discharge machining (EDM) M2 grade high speed steel workpiece. To evaluate the machinability, electrode wear ratio (EWR) and surface roughness (SR) were the two responses observed. Discharge current, pulse on time, duty cycle, and gap voltage were the controllable process parameters. It was found that EWR reduced up to 20% by cryogenic cooling of electrode. With electrode cooling, SR was also found to have been reduced after machining. The effect of process parameters on EWR and SR were also analysed. It was found that for EWR, discharge current, pulse on time, and duty cycle has the most significant effect, while pulse on time and discharge current have the most significant effect on SR. EWR and SR were found to be lower in cryogenic assisted EDM as compared to conventional EDM for the same set of process parameters. The shape of the electrode has also been measured, and it was found that the shape retention was better in cryogenic assisted EDM as compared to conventional EDM [6].

J. M. Jefferson et.al this paper showed that minimized unit material removal is the essential character of any micromachining processes which was enhanced by cryogenic treatment of tool electrodes. From the experimental study, it was observed that, there is significant reduction in TWR. The following interesting results were obtained due to cryogenic treatment: TWR decreased by 58% for tungsten, 51% for brass, and 35% for copper electrodes; MRR decreased by 55% for tungsten, 39% for brass, and 34% for copper electrodes; Electrical resistance decreased by 17.95% for tungsten, 10.4% for copper, and 4.5% for brass electrodes; Micro hardness values increased by 120% for tungsten, 93% for brass, and 17% for copper electrodes; The average crystallite size is reduced by 29% for brass, 12% for copper, and 5% for tungsten electrodes [7].

Y. Yildiz et.al in this study, beryllium-copper alloy was subjected to around -150° F for cold treatment and to around -300° F for cryogenic treatment and the effects of these cold and cryogenic treatments on the machinability of beryllium-copper workpieces in electro discharge machining have been investigated. Experimental results showed about 20-30 % increase in material removal rate of cold and cryogenic treated workpieces. Variations in electrode wear rate, surface roughness and average white layer thickness were found to be marginal [8].

Murali Meenakshi Sundaram et.al Cryogenic treatment is a heat treatment process in which the specimen is subjected to an extremely low temperature of the order of -300° F and below, to cause beneficial changes in the material properties. The advantages of cryogenic treatment include relieved residual stresses, and better electrical properties. Electro discharge machining (EDM) is a well-known non-traditional machining process in which electrical energy is converted to thermal energy to remove material by melting and evaporation from electrically conductive materials. The process performance of EDM is affected by several factors including the material properties. In this study, the effect of cryogenic treatment on the performance of EDM is investigated experimentally. Copper tool electrodes were subjected to two different treatment methods, namely cold treatment (around - 150° F) and deep cryogenic treatment (around -300° F). Using these electrodes, experiments were conducted to study the effect of various process parameters. Significant improvement in material removal rate was observed for EDM with cryogenically treated tools. However, their effect on tool wear is only marginal [9].

Anand Pandey et.al this research article rotary pin type electrode has been used as tool electrode with 45° thread angle. The study has been done using cryogenically treated Cu-tool electrode to fabricate hole on Ni-based super alloy (Inconel-718) using Taguchi's Methodology. In the present research article machinability in terms of material removal rate, MRR have been discussed using Taguchi's Methodology. The investigation reports the benefits of cryogenically treated Cu tool electrode for improved metal removal, improving machinability with less wear and high surface quality. The rotating effect with helical threads assists in improving MRR. In addition, main effects plots for S/N ratios has been developed and analysed [10].

Jatinder Kapoor et.al in this article, the effect of cryogenic treatment on the brass wire electrode used in wire electrical discharge machining is investigated. Deep cryogenic (-184 0C) treatment is given to the brass wire electrode. The microstructure and crystalline phase of deep and non-cryogenic treated brass wire electrodes is observed by scanning electron microscope and X-Ray diffraction. The experimental results show that the structure is more refined in deep cryogenic treatment as compared to non-

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cryogenic treatment. The electrical conductivity of deep electrode is greatly improved. The effect of deep cryogenic treatment on the brass wire electrode is also investigated for the performance of wire electrical discharge machining. Taguchi experimental design has been applied to investigate the optimal parameters for maximum material removal rate. The ANOVA analysis indicates that type of wire, pulse width, time between two pulses and wire tension are significant factors for maximization of material removal rate. The cryogenic treatment results in improved material removal rate [11].

Zhiguang Huia et.al the discharge characteristics and discharge gap of machining Ti–6Al–4V titanium alloy by cryogenically cooled tool electrode electrical discharge machining (EDM) in distilled water were investigated in this study using the mono-pulse discharge method. The influence of the cryogenically cooled tool electrode on the discharge gap and the initial maintaining voltage between the electrode and workpiece were analysed under various temperatures. Test results showed the initial maintaining voltage of the cryogenically cooled tool electrode EDM was lower than that of conventional EDM. The discharge gap of the cryogenically cooled tool electrode EDM was also smaller than that of conventional EDM, which improved the copying accuracy of die-sinking EDM. A comparative experiment of machining Ti–6Al–4V titanium alloy was carried out by using cryogenically cooled tool electrode EDM and conventional EDM, lower electrode wear, higher material removal ratio, and higher corner size machining accuracy was obtained by using cryogenically cooled tool electrode EDM [12].

L. Tang et.al Ti–6Al–4V is widely used in the aerospace, automobile, and biomedical fields, but is a difficult-to-machine material. Electrical discharge machining (EDM) is regarded as one of the most effective approaches to machining Ti–6Al–4V alloy, since it is a non-contact electro-thermal machining method, and it is independent from the mechanical properties of the processed material. This paper aims to combine grey relational analysis and Taguchi methods to solve the problem of EDM parameters optimization. From the viewpoint of health and environment, tap water as working fluid has good working environment, since it does not release harmful gas. The process parameters include discharge current, gap voltage, lifting height, negative polarity and pulse duty factor. The electrode wear ratio (EWR), material removal rate (MRR) and surface roughness (SR) as objective parameters are chosen to evaluate the whole machining effects. Experiments were carried out based on Taguchi L9 orthogonal array and grey relational analysis, and then verified the results through a confirmation experiment and compared the machining parameters and gives MRR increased from 1.28 mm3/min to 2.38 mm3/min, EWR decreased from 0.14 to 0.10 mm3/min and SR decreased from Ra 2.37 μm to Ra 1.93 μm. The process parameters sequenced in order of relative importance are: the ratio of pulse width to pulse interval, discharge current, lifting height and gap voltage. The results showed that using tap water machining Ti–6Al–4V material can obtain high MRR, decrease the machining cost and have no harmful to the operators and the environment [13].

Hari Singh et.al this research shows that Cryogenic treatment (“Cryo”) is a supplementary process to improve the properties of metals like high carbon high chromium alloy tool steels (D-3) which are increasingly used in manufacturing high-performance cutting tools (dies and punches), blanking and punching tools, extrusion tools, parts of aerospace and automotive industries, etc. The purpose of this study is to investigate the effect of parameters like pulse width, time between two pulses, maximum feed rate, servo reference mean voltage, short pulse time, and wire mechanical tension, on cutting rate (CR) of cryogenic-treated D-3 in wire electrical discharge machining. An L27 orthogonal array has been used to conduct experiments and statistically evaluate the experimental data by analysis of variance (ANOVA). It is seen that CR decreases with increase in pulse width, time between two pulses, and servo reference mean voltage. CR first decreases and then increases with increase in wire mechanical tension. The confirmation experiments have also been conducted to validate the results obtained by Taguchi technique [14].

Munmun Bhaumik et.al powder mixed electro discharge machining (PMEDM) is further advancement of conventional electro discharge machining (EDM) where the powder particles are suspended in the dielectric medium to enhance the machining rate as well as surface finish. Cryogenic treatment is introduced in this process for improving the tool life and cutting tool properties. In the present investigation, the characterization of the cryotreated tempered electrode was performed. An attempt has been made to study the effect of cryotreated double tempered electrode on the radial overcut (ROC) when SiC [15].

Chinmay P. Mohanty et.al this study presents experimental investigation to assess influence of cryogenic treatment of electrodes on machinability in powder-mixed electrical discharge machining (PMEDM). Response surface methodology is used to extract maximum process related information with less number of experimental runs. The machining characteristics of the process are evaluated in terms of material removal rate (MRR), electrode wear ratio (EWR) and surface roughness which are function of machining parameters viz. open circuit voltage, discharge current, pulse-on-time, duty factor, concentration of fine graphite powder and cryogenically treated work tool pair. The study reveals that discharge current, pulse-on-time, concentration of powder and work-tool pair exhibit significant effect on all the performance measures. It is also observed that treatment to both the electrodes results in more beneficial in comparison to treatment of either the tool or work piece. Finally, a novel multi-objective particle swarm optimisation algorithm (MOPSO) has been proposed in order to achieve optimal Pareto front powder is mixed in the kerosene

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dielectric during electro discharge machining of AISI 304. The process performance has been evaluated by means of ROC when peak current, pulse on time, gap voltage, duty cycle and powder concentration are considered as process parameters and machining is performed by using tungsten carbide electrodes (untreated and double tempered electrodes). A regression analysis was performed to correlate the data between the response and the process parameters. Microstructural analysis was carried out on the machined surfaces. Least radial overcut was observed for conventional EDM as compared to powder mixed EDM. Cryotreated double tempered electrode significantly reduced the radial overcut than untreated electrode [16].

Vineet Srivastava et.al this work shows the parametric study on EDM process using ultrasonic assisted cryogenically cooled copper electrode (UACEDM) during machining of M2 grade high speed steel has been performed. Electrode wear ratio (EWR), material removal rate (MRR) and surface roughness (SR) was the three parameters observed. Discharge current, pulse on time, duty cycle and gap voltage were the controllable process variables. The effect of process variables on EWR, MRR and SR has been analysed. The MRR, EWR and SR obtained in EDM process with normal electrode, cryogenically cooled electrode and ultrasonic assisted cryogenically cooled electrode have been compared. EWR and SR were found to be lower in UACEDM process as compared to conventional EDM for the same set of process parameters, while MRR was at par with conventional EDM process. The surface integrity of work piece machined by UACEDM process has been found to be better as compared to conventional EDM process. The shape of the electrode has also been measured and it was found that the shape retention was better in UACEDM process as compared to conventional EDM process. Thus in the present work UACEDM process has been established to be better than conventional EDM process due to better tool life, tool shape retention ability and better surface integrity [17].

III.CONCLUSIONS

Most of the research work has been reported on WEDM but limited research work on Die-sinking electrical discharge machining process. The work published so far consists of experiments which conclude the effect of tool material on the surface roughness using copper as electrode material. An experiment consisting of comparative study between C.T. Cupro-Nickel Electrode materials for machining of Inconel 718 with Cupro-Nickel is not conducted yet. The material removal rate (MRR) is low in case of EDM. In this area more work can be done in order to obtain higher MRR in the EDM Very limited investigation has been observed for optimization of electrode wear for different electrode materials. It is evident from the literature reviewed that electrode materials play a vital role in giving the optimum values of the performance parameters. No such work is observed in the literature review in case of Cupro-Nickel electrode as tool material.

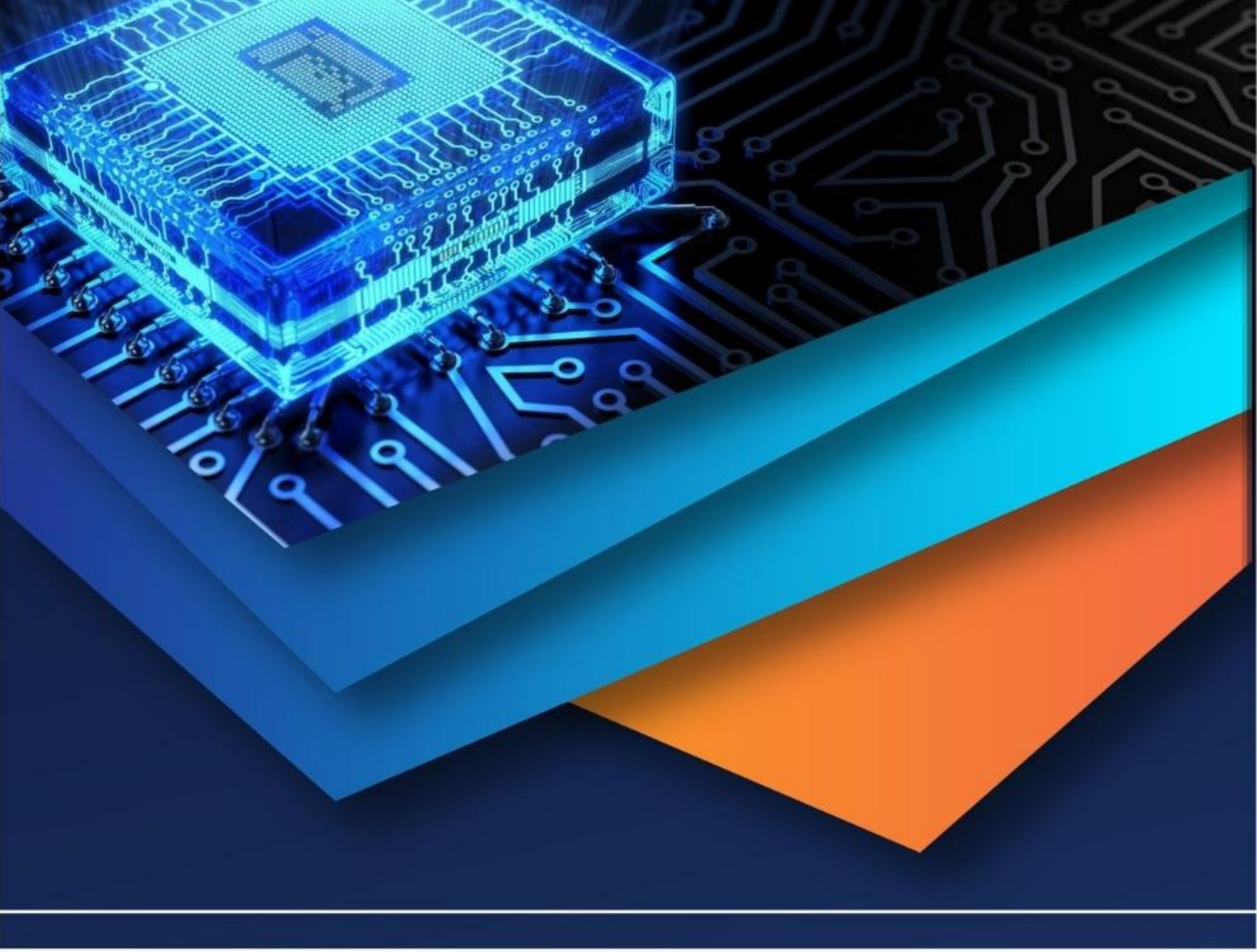
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