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Optimisation of Machining Parameters in Wire Cut EDM for Cemented Tungsten Carbide using Taguchi Technique

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***Abstract:** Accompanying the development of production, aerospace and automotive industries, the demand for alloy materials having high hardness, toughness and impact strength are increasing. As these materials pose severe difficulty to be machined by conventional methods, Wire-cut Electric Discharge Machining (Wire EDM) machines are employed to machine them. The ultimate requirement of any machining process being fine surface finish and faster material removal is accurately satisfied by wire-cut EDM process. Hence this project aims at obtaining the best surface finish and higher MRR for Cemented Tungsten Carbide by optimizing various process parameters affecting the machining conditions. In this work Grey-Taguchi method were used and identified the best parameter (Pulse On Time, Pulse Off Time and Wire Feed Rate) for machining the Tungsten carbide material in Wire EDM.*
***Keywords:** Wire cut Edm, Dielectric Fluid, Electrode material, MRR*

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional, thermo electrical process, which erodes material from the work piece by a series of discrete sparks between the work and tool electrode immersed in a liquid dielectric medium. These electrical discharges melt and vaporize minute amounts of the work material, which are then ejected and flushed away by the dielectric. A wire EDM generates spark discharges between a small wire electrode and a work piece with de-ionized water as the dielectric medium and erodes and work piece to produce complex two- and three – dimensional shapes according to a numerically controlled (NC) path. The main goals of WEDM manufacturers and users are to achieve a better stability and higher productivity of the WEDM process. As newer and more exotic materials are developed, and more complex shapes are presented, conventional machining operations continue to reach their limitations and the increased use of the WEDM in manufacturing continues to grow at an accelerated rate. Wire electrical discharge machining manufactures and users emphasize on achievement of higher machining productivity with a desired accuracy and surface finish. However, due to a large number of variables even a highly skilled operator with a state-of the art WEDM is rarely able to achieve the optimal performance.

II. EXPERIMENTAL SET-UP AND WORKING

In wire electrical discharge machining (WEDM), a thin single-strand metal wire, usually brass, is fed through the workpiece, submerged in a tank of dielectric fluid, typically deionized water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods.

The wire, which is constantly fed from a spool, is held between upper and lower diamond guides. The guides, usually CNC-controlled, move in the x–y plane. On most machines, the upper guide can also move independently in the z–u–v axis, giving rise to the ability to cut tapered and transitioning shapes (circle on the bottom square at the top for example). This allows the wire-cut EDM to be programmed to cut very intricate and delicate shapes. The upper and lower diamond guides are usually accurate to 0.004mm, and can have a cutting path or kerf as small as 0.12mm using Ø 0.1mm wire, though the average cutting kerf that achieves the best economic cost and machining time is 0.335mm using Ø

0.25mm brass wire. The reason that the cutting width is greater than the width of the wire is because sparking occurs from the sides of the wire to the work piece, causing erosion. Spools of wire are long—an 8 kg spool of 0.25mm wire is just over 19 kilometers in length. Wire diameter can be as small as 20µm and the geometry precision is not far from

+/- 1µm.

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III. WORKPIECE MATERIAL

A. Tungsten Carbide

Tungsten carbide (WC) is an inorganic chemical compound containing equal parts of tungsten and carbon atoms. Colloquially, tungsten carbide is often simply called carbide. In its most basic form, it is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, tools, abrasives, as well as jewelry. Tungsten carbide is approximately three times stiffer than steel, with a Young's modulus of approximately 550 GPa, and is much denser than steel or titanium. It is comparable with corundum (α-Al_2O_3 or sapphire) in hardness and can only be polished and finished with abrasives of superior hardness such as silicon carbide, cubic boron nitride and diamond. The density of the material is 15.8g/cm^3.

Figure 3.1 Tungsten carbide

B. Mechanical Properties of Carbides

Strength - Tungsten carbide has very high strength for a material so hard and rigid. Compressive strength is higher than virtually all melted and cast or forged metals and alloys.

Rigidity - Tungsten carbide compositions range from two to three times as rigid as steel and four to six times as rigid as cast iron and brass. Young's Modulus is up to 94,800,000 psi.

High resistance to deformation and deflection is very valuable in those many applications where a combination of minimum deflection and good ultimate strength merits first consideration. These include spindles for precision grinding and rolls for strip or sheet metal.

Impact Resistant - For such a hard material with very high rigidity, the impact resistance is high. It is in the range of hardened tool steels of lower hardness and compressive strength.

Heat and oxidation resistance - Tungsten-base carbides perform well up to about 1000°F in oxidizing atmospheres and to 1500°F in non-oxidizing atmospheres

Low temperature resistance (cryogenic properties) - Tungsten carbide retains toughness and impact strength in the cryogenic temperature ranges. (-453°F.)

Thermal Conductivity - Tungsten carbide is in the range of twice that of tool steel and carbon steel.

Electrical Conductivity - Tungsten carbide is in the same range as tool steel and carbon steel.

Specified Heat - Tungsten carbide ranges from about 50% to 70% as high as carbon steel.

Weight - The specific gravity of tungsten carbide is from 1-1/2 to 2 times that of carbon steel.

IV. METHODOLOGY

A. Taguchi Method

Taguchi Method is a system of cost-driven quality engineering that emphasizes the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and find cost- effective, robust designs for large-scale production and the marketplace. Shop-floor techniques provide cost-based, real-time methods for monitoring and maintaining quality in production. Taguchi Methods allow a company to rapidly and accurately acquire technical information to design and produce low-cost, highly reliable products and processes. Its most advanced applications allow engineers to develop flexible technology for the design and production of families of high quality products, greatly reducing research, development, and delivery time.

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In general, the farther upstream a quality method is applied, the greater leverage it produces on the improvement, and the more it reduces the cost and time. Most typical applications of Taguchi Methods thus far have centered around two main areas:

1) Improving an existing product
2) Improving a process for a specific product

Tremendous additional benefits can be derived from improving the robustness of generic technology (in R&D) so that it is applicable to a family of present and future products and processes. This application, called Robust Technology Development is currently being practiced by only a few leading companies worldwide. Farther downstream, Taguchi's methods for what he terms "on-line" quality control (Manufacturing Process Control) can achieve a more cost-effective process control.

Taguchi Methods require a new way of thinking about product development. These methods differ from others in that the methods for dealing with quality problems center on the design stage of product development, and express quality and cost improvement in monetary terms.

The key to competitive leadership is the timely introduction of high quality products at the right price. Achieving maximum efficiency and effectiveness in the research and development process is critical to this effort.

The DOE with Taguchi approach is divided into three main phase, which encompass all experimentation approaches and they are

a) Planning Phase
b) Conducting Phase
c) Analysis Phase

B. Levels of the Factors

The levels of factors used in the experiment is shown in Table 4.1.

Sl.No	Symbol	Cutting Parameters	Levels			Units
			1	2	3	
1	A	Pulse on time (Ton)	2	4	6	µ Sec
2	B	Pulse off time (Toff)	2	4	6	µSec
3	C	Wire feed (WF)	3	4	5	mm /min

C. Selection Criteria For Orthogonal Array

The conditions for selection of orthogonal array used in the experiment are

Degree of freedom (DOF) for factors : levels – 1.

DOF for OA : No. of trails – 1. DOF of L9 orthogonal array: 9 – 1 = 8.

The orthogonal array is selected based on the following conditions.

$\sum DOF_i \leq$ DOF of OA, number of factors : i = 1 to n

For three factors and three levels L9 orthogonal array is used. Table 5.2 Shows the Standard L9 Orthogonal array.

Experiment No.	Pulse On time	Pulse Off time	Wire Feed (m/min)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 4.2 L9 Orthogonal array

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Experiment No.	Pulse On time (µs)	Pulse Off time (µs)	Wire Feed (m/min)
1	2	2	3
2	2	4	4
3	2	6	5
4	4	2	4
5	4	4	5
6	4	6	3
7	6	2	5
8	6	4	3
9	6	6	4

Table 4.3 Values of Factors assigned to Orthogonal Array

V. RESULTS AND DISCUSSIONS

The selected three parameters have different influences on the machining performance. The significant parameters are found by the analysis of variance (ANOVA) and the optimal cutting parameters are obtained using the main effects plot.

Experiment No.	Pulse On time (µs)	Pulse Off time (µs)	Wire Feed (m/min)	MRR (g/min)	SURFACE ROUGHNESS, Ra (µm)
1	2	2	3	0.03513	3.2354
2	2	4	4	0.03384	3.4628
3	2	6	5	0.03287	2.6842
4	4	2	4	0.03835	3.8170
5	4	4	5	0.03739	3.2202
6	4	6	3	0.03642	3.6702
7	6	2	5	0.04190	4.1022
8	6	4	3	0.04093	3.8518
9	6	6	4	0.03964	3.5348

Table 5.1 L9 orthogonal array with responses

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A. Optimization Steps Using Grey-Taguchi Method

EXPERIMENT NO.	PERFORMANCE MEASURES		S/N RATIO	
	MRR (g/min)	SURFACE ROUGHNESS, Ra (µm)	MRR(db)	SURFACE ROUGHNESS, Ra (db)
1	0.03513	3.2354	- 29.086	- 10.198
2	0.03384	3.4628	- 29.411	- 10.788
3	0.03287	2.6842	- 29.664	- 8.576
4	0.03835	3.8170	- 28.325	- 11.634
5	0.03739	3.2202	- 28.545	- 10.158
6	0.03642	3.6702	- 28.773	- 11.294
7	0.04190	4.1022	- 27.556	- 12.260
8	0.04093	3.8518	- 27.759	- 11.713
9	0.03964	3.5348	- 28.037	- 10.967

Table 5.2 S/N ratio values

EXPERIMENT NO	CONTROL FACTORS			Normalized S/N Ratios	
	A	B	C	MRR	Ra
1	1	1	1	0.27419	0.44028
2	1	2	2	0.12002	0.60043
3	1	3	3	0	0
4	2	1	2	0.63519	0.83008
5	2	2	3	0.53083	0.42942
6	2	3	1	0.42268	0.73779
7	3	1	3	1	1
8	3	2	1	0.90370	0.85152
9	3	3	2	0.77182	0.64902

Table 5.3 The Normalized S/N Ratio Values

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EXPERIMENT NO	CONTROL FACTORS			Grey Relation Co-efficient		
	A	B	C	MRR	Ra	GREY GRADE
1	1	1	1	0.40789	0.47182	0.43986
2	1	2	2	0.36232	0.55582	0.45907
3	1	3	3	0.33333	0.33333	0.33333
4	2	1	2	0.57816	0.74636	0.66226
5	2	2	3	0.51591	0.46704	0.98295
6	2	3	1	0.46411	0.65599	0.56005
7	3	1	3	1	1	1
8	3	2	1	0.83850	0.77103	0.80477
9	3	3	2	0.68664	0.58756	0.63710

Table 5.4 Grey Relation Co-efficient and Grey Relational Grade

Figure 5.1 Grey Relational Grades for Maximum MRR and Minimum Ra

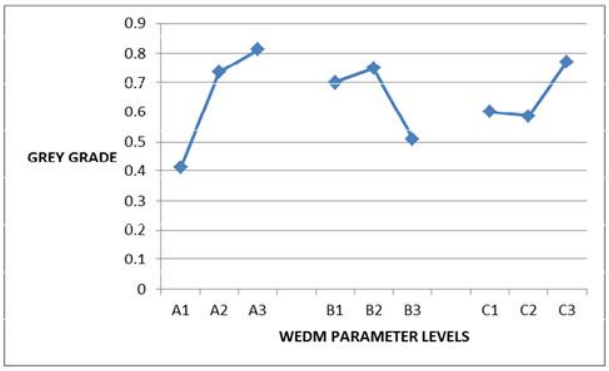
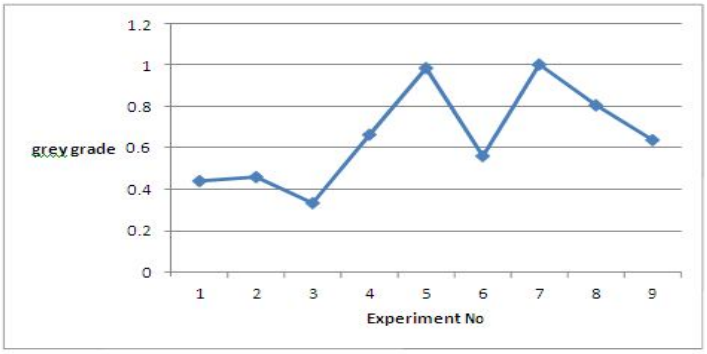


Figure 5.2 Response Graph of Average Grey Relational Grade



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B. Analysis Of Variance Table

PARAMETERS	SUM of SQUARES	VARIANCE	DOF	F test values	CONTRIBUTION %
PULSE ON TIME	4.9754	2.4877	2	2.9219	51.629
PULSE OFF TIME	1.7743	0.8872	2	1.0420	18.412
WIRE FEED	1.1842	0.5921	2	0.6954	12.288
ERROR	1.7029	0.8514	2		17.671
TOTAL	9.6368		8		100

Table 5.5 Anova Table For Surface Roughness

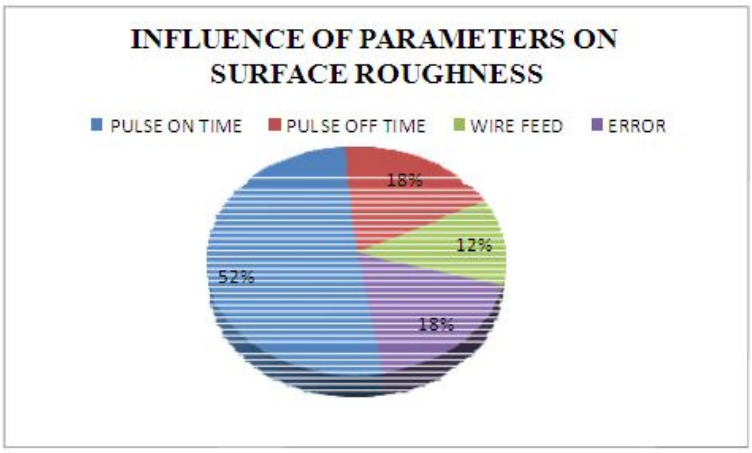

Fig.5.3 Percentage Contribution of Each Factor on Surface Roughness

PARAMETERS	SUM of SQUARES	VARIANCE	DOF	F test values	CONTRIBUTION %
PULSE ON TIME	3.8572	1.9286	2	2571.467	90.927
PULSE OFF TIME	0.3782	0.1891	2	252.133	8.915
WIRE FEED	0.0052	0.0026	2	3.467	0.123
ERROR	0.0015	0.00075	2		0.035
TOTAL	4.2421		8		

Table 5.6 ANOVA TABLE FOR MATERIAL REMOVAL RATE

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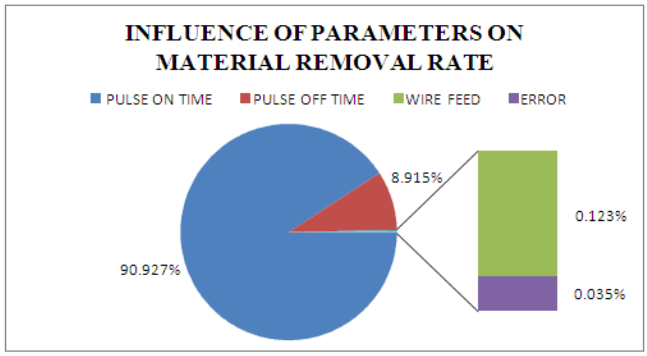

Fig 5.4 The percentage contribution on Material Removal Rate

VI. CONCLUSION

On the basis of experimental results, calculated S/N ratio, analysis of variance (ANOVA) and 'F' test values, the following conclusions are drawn for machining of Tungsten carbide in WEDM.

The pulse on time is the most significant machining parameter for surface roughness (SR) for machining of Tungsten carbide.

The pulse on time is the most significant machining parameter for material removal rate (MRR) while machining of Tungsten carbide.

For higher material removal rate, the recommended parametric combination is pulse on time at level 3, pulse off time at level 1 and wire feed rate at level 3 for machining of Tungsten carbide.

For better surface finish the recommended parametric combination is pulse on time at level 1, pulse off time at level 3 and wire feed rate at level 3 for machining of Tungsten carbide.

While applying the Grey-Taguchi method, The Material Removal Rate shows an increased value of 0.04190 g/min to 0.04512 g/min and the Surface Roughness shows a reduced value of 4.1022µm to 3.7253µm respectively, which are positive indicators of efficiency in the machining process.

For better surface finish and higher material removal rate, the recommended parametric combination is pulse on time at level 3, pulse off time at level 2 and wire feed rate at level 3 for machining of Tungsten carbide.

Thus, it can be concluded that the Grey-Taguchi Method, is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process, when using the multiple performance characteristics such as MRR (Material Removal Rate) and Surface Roughness for machining the Tungsten carbide.

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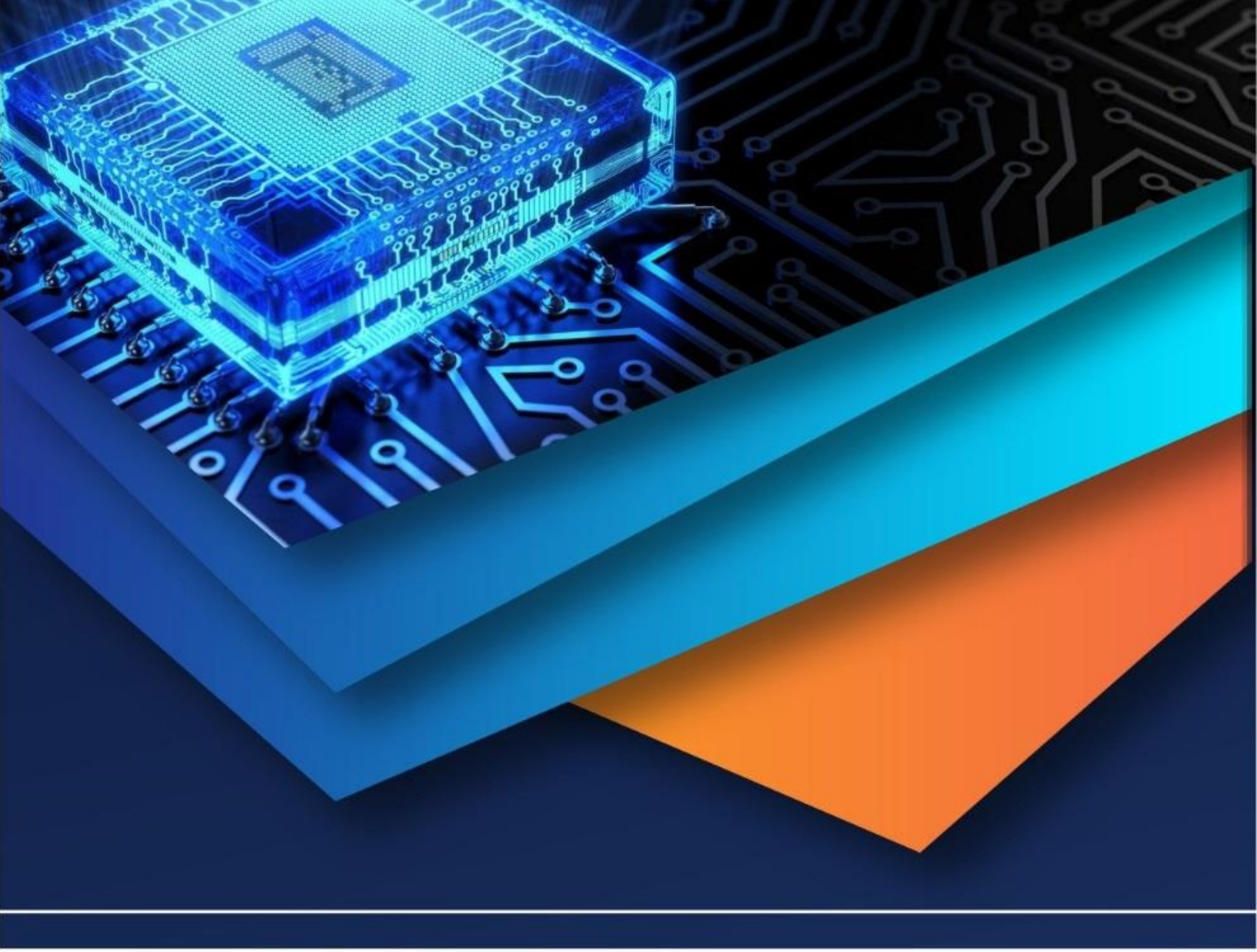

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