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Evaluation of Hardness and Compression Properties of Aluminum Alloy Using Taguchis Optimization Technique

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Abstract : In recent years Aluminium and its alloys are becoming more and more popular in the manufacture of automobile and its body parts. One of the most commonly used aluminium alloy for structural application is AL 7075 alloy. In this paper the study focus on the mechanical and tribological properties of AL 7075 alloy by varying the percentage of alloying elements. Taguchi method is used to optimize the number of specimens with specific composition. The experiments consist of 9 tests according to L9 orthogonal array. However signal to noise ratio analysis has been carried out to determine optimal parametric conditions which yield maximum compression strength and maximum hardness. Finally we found the best confirmative specimens for the future studies.

Keywords: AL 7075 Alloy, Taguchi's Technique, Die Casting, compressive strength, Hardness Number.

I. INTRODUCTION

Aluminium is the most widely found metal on the planet. Aluminium is produced with Bauxite as raw material, which is a clay like soil type found mostly in a belt around the equator. Aluminium is bluish-white in appearance in its purest form and very ductile in nature. The name Aluminium was derived from a Latin word 'alumen'. Aluminium is also the 3rd most available element on earth's crust. Aluminium is a soft, lightweight and silvery metal which is also called as the "Wonder Metal Of The 20th Century" for its amazing properties which paved its way into commercial use. Aluminium alloys are alloys in which the predominant material is aluminium (Al) along with copper, silicon, manganese, magnesium, zinc and tin. Alloys are basically classified into wrought and cast alloys, which are further classified as heat treatable and non-heat treatable alloys. Aluminium alloy 7075 is an aluminium alloy, with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability. It has lower resistance to corrosion than many other Al alloys, but has significantly better corrosion resistance than the 2000 alloys. Its relatively high cost limits its use to applications where cheaper alloys are not suitable. Aluminium 7075 is the major alloy in 7000 Series and Zinc is the major alloying element in this series. Aluminium 7075 possesses high static strength and is used in airframe structures and for highly stressed parts.

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. In this work L9 is sufficient. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array. The last column can be kept dummy, but no row should be left out. Once the orthogonal array is selected, the experiments are selected as per the level combinations. It is important that all experiments are conducted.

S/N ratio: In Taguchi's design method the design parameters (factors that can be controlled by designers) and noise factors (factors that cannot be controlled by designers, such as environmental factors) are considered influential on the product quality.

II. MATERIALS AND METHODS

A. Material Compositions

The material used for present work was AL 7075 alloy. Table1 shows the composition of Aluminium-7075 alloy according to ASM standards is as shown below.

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Table-1: chemical composition of AL 7075 alloy.

COMPONENT	Wt.%	COMPONENT	Wt.%	COMPONENT	Wt.%
AL	87.1-91.4	Mg	2.1-2.9	Si	Max 0.4
Cr	0.18-0.28	Mn	Max 0.3	Ti	Max 0.2
Cu	1.2-2	Zn	5.1-6.1	Fe	Max 0.5

B. Selection of Parameters

In the present work, experiments are carried out using taguchi L9 orthogonal array. Experiments were conducted considering 3 parameters: Zinc, Magnesium & Aging time. Table2 shows the values of various parameters used for experiments.

Table-2: Composition parameters.

Sl. No	Composition Parameters	Levels		
		1	2	3
01	Zinc (Zn)	5.1	5.6	5.9
02	Magnesium (Mg)	2.1	2.5	2.9
0.3	Aging Time(in hours)	3	5	7

C. *Methodology*

1) Taguchi Approach: Taguchi's L-9 orthogonal array was selected for optimization of the experimental work. The composition of the alloy specimens were decided according to the outcome of Taguchi analysis. Taguchi's L-9 design includes a 3 parameter-3 level orthogonal array, where the 3 parameters taken into consideration are % Zinc, % Magnesium and Aging Time in hours. All the 3 parameters were given 3 Levels and the overall OA (orthogonal array) was constructed, which consist of 9 specimens of varying compositions of % Zinc, % Magnesium and Aging hours. The remaining percentage composition is kept constant as shown in table 3.

Tabel-3: Aluminium Alloy-7075 Material Composition

SL NO.	%Zn	%Mg	%Si	%Mn	%Fe	%Ti	%Cu	%Cr	%Al	Aging time
1	5.1	2.1	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	3
2	5.1	2.5	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	5
3	5.1	2.9	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	7
4	5.6	2.1	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	5
5	5.6	2.5	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	7
6	5.6	2.9	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	3
7	6.1	2.1	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	7
8	6.1	2.5	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	3
9	6.1	2.9	0.3	0.2	0.3	0.2	1.4	0.2	Bal.	5

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2) Material Preparation: AL 7075 is melted in the electric furnace at 800^0C. After melting required quantity of pure zinc and magnesium is added and continued in the same temperature. Later the molten metal is stirred and poured into the metal die to get the castings. The casted specimens once removed from the die are immediately soaked in the furnace at 480°C for 2 hours with maximum deviation in the temperature being ±5°C. This solution heat treatment process allows sufficient time for the casted alloys constituents to enter into the solid solution, followed by rapid cooling by quenching the specimen in water at room temperature for 10 seconds. These heat treated specimens were subjected to artificial aging (also called Age hardening). In this process the specimens were subjected to a temperature of 175°C with maximum deviation being ±5°C in a muffle furnace as per the Aging hours decided for the Taguchi's design. All the 9 casted specimens were machined according to ASTM standards for the test to be carried out.

Fig.1: Casted Specimens

III. RESULTS AND DISCUSSIONS

A. Microscopic Tested Results

1) Nature of Test: Microstructure

2) Equipment Used: Optical metallurgical microscopic (Model: NIKON Epiphot 2000)

The specimens were manually polished adopting standard polishing procedure. Keller's reagent was then used to etch the polished specimens. Etched specimens were observed under the microscopic at magnifications of 200X.

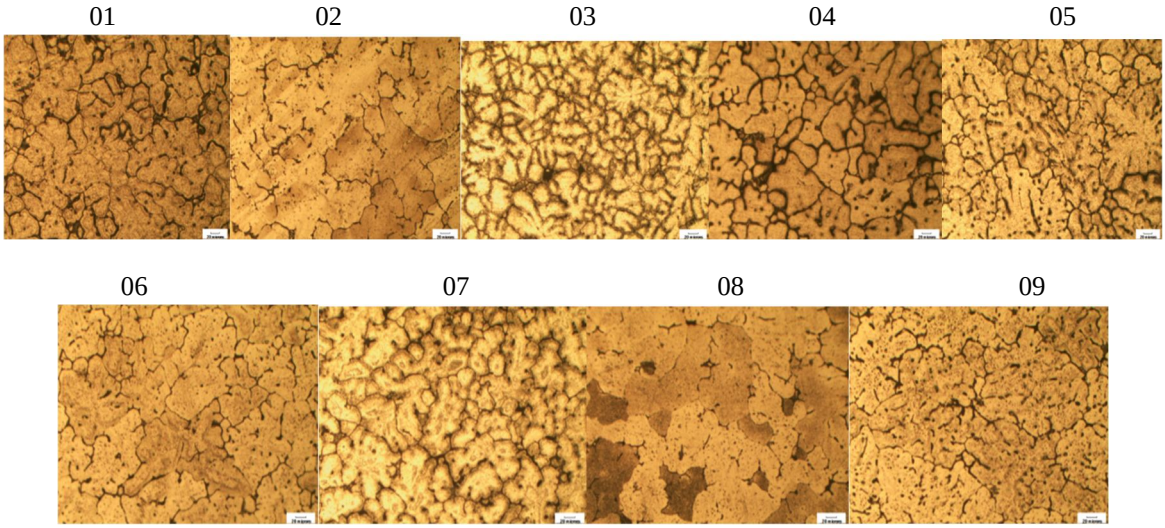

Fig.2: Optical Microscopic view of all 9 specimens.

Above figures shows the microstructure of AL 7075 alloy. Micrograph clearly reveals minimal micro porosity in the castings. No clustering was observed in the specimens. There is good bonding in alloys and dense grains which reveals maximum hardness and minimum wear resistance.

B. Hardness Test

Brinell hardness test was conducted to test hardness of the material. A load of 187.5 Kg-f was applied for about 15sec followed by which the indenttion was measured under a micrometer microscope and the Brinell hardness no. was calculated.

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C. Compression Test Results

Compression test was conducted for all the 9 alloy specimens to determine the deformation, stress, and young's modulus from the stress-strain curve. Universal Testing Machine was used to compress the specimen and values of deformation were recorded for equal load intervals.

D. Experimental Observations

Based on the selected range of %Zn, %Mg & Aging time, the Specific wear rate and Hardness number are determined which is represented in table4.

Table-4: Experimental Results.

Sl. No.	Zn	Mg	Aging Hours	Compression strength	Hardness number
1	5.1	2.1	3	539.59	100.77
2	5.1	2.5	5	559.57	111.35
3	5.1	2.9	7	650.542	111.35
4	5.6	2.1	5	585.491	106.06
5	5.6	2.5	7	628.165	155.61
6	5.6	2.9	3	599.847	117.88
7	6.1	2.1	7	650.396	124.42
8	6.1	2.5	3	650.540	121.14
9	6.1	2.9	5	563.806	111.35

From the above table it can be conclude that specimen 5 has maximum hardness compared to other specimens and specimen 3 has minimum wear resistance compared to other specimens. This is also clear from their microstructure which has dense grains indicating better hardness. As hardness increases the wear resistance decreases.

1) *Optimization By S/N Ratio:* Minitab statistical software has been used for the analysis of the experimental work. The taguchi method use a statistical measure of performance called signal to noise ratio. The S/N ratio is used to measure the deviation of the performance characteristic from the desired values.
2) *Analysis of S/N Ratio:* Lager-the-better performance characteristic is selected to obtain Compression strength. Lager-the -better performance characteristic is selected to obtain hardness number of the specimens.

Table-5: Response Table for Signal to Noise Ratios (Larger is better)

Level	Zn	Mg	Aging time
1	55.29	55.42	55.49
2	55.62	55.73	55.11
3	55.85	55.62	56.16
Delta	0.56	0.31	1.05
Rank	2	3	1

Table-6: Response table for Hardness Number (Lager-the-better).

Level	Zn	Mg	Aging time
1	55.29	55.42	55.49
2	55.62	55.73	55.11
3	55.85	55.62	56.16
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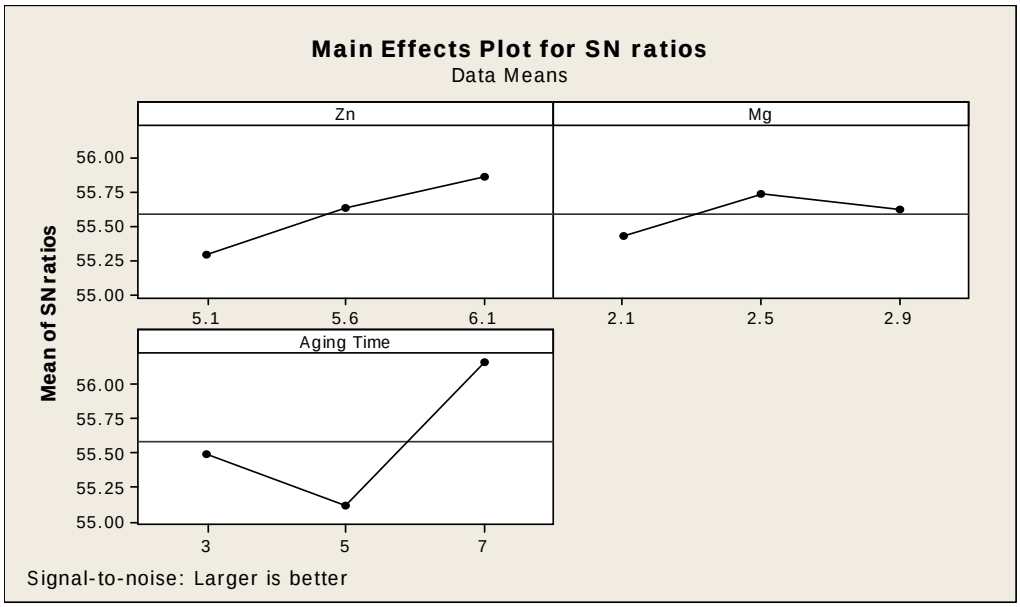

Fig.3: Main Effects Plot of compression strength.

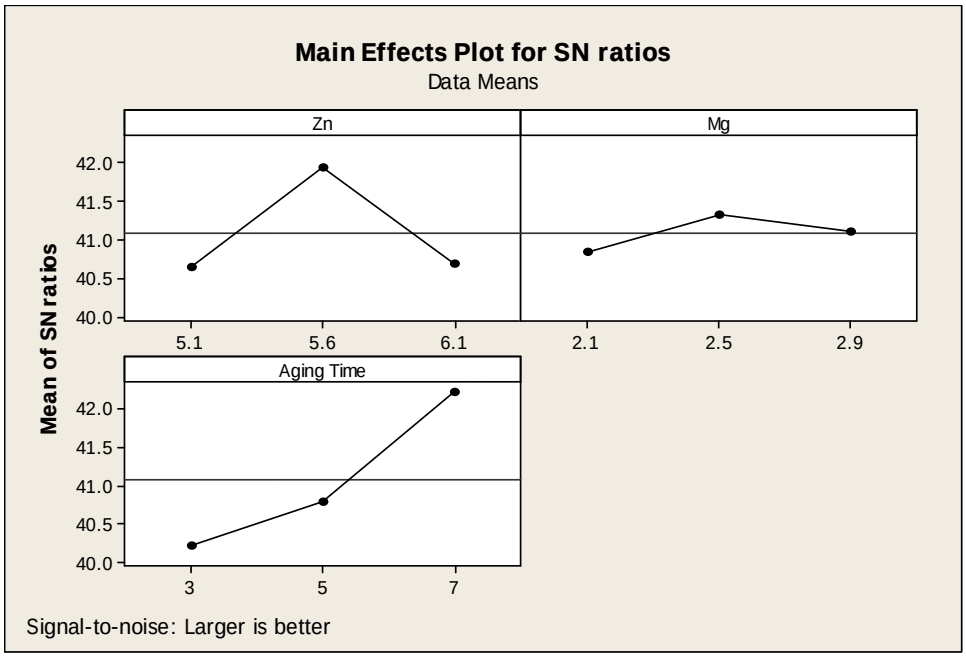

Fig.4: Main Effects Plot of Hardness Number.

The optimized composition for Compression strength is %Zn-6.1, %Mg-2.5, Aging time-7hrs The above composition is casted and experiment is carried out resulting in ultimate compression strength of 628.165 N/mm^2. A deviation of 3.41% and 3.44% was found in the Compression Strength value when compared with the closest composition in the earlier results. That is with Specimen 8 & 9. Also comparing it with the highest value of Compression Strength the deviation was 3.54%, it can be concluded that the Results are satisfactory since the deviation was under 10%.

From the response table 6 and Fig.4 the optimized composition for Hardness is %Zn-5.6, %Mg-2.5 and Aging time-7hrs. The above composition is casted and tested for hardness resulting in BHN=147.39 a deviation of 5.2% was found in the BHN value when compared with the closest composition in the earlier results. Also comparing it with the highest value of Hardness the deviation was 5.2%, it can be concluded that the results are satisfactory since the deviation was under 10%.

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E. Fem Analysis

As per the numerical analysis the deformation and stress distribution obtained for each Al-7075 alloy specimen was to be optimum compared to analytical results

It is the re-casted specimen after the application of taguchi method.

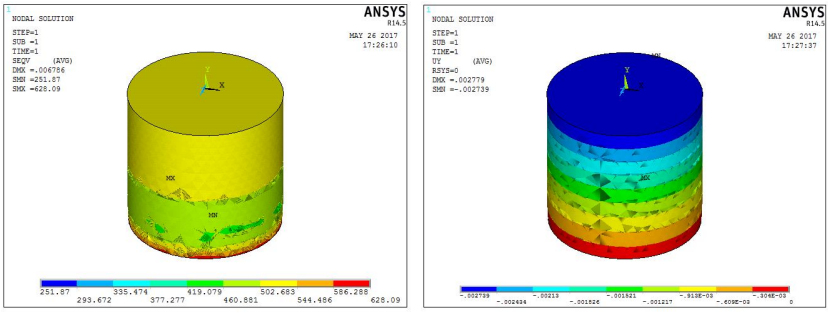

Fig.5 Von Mises stress & Deformation plot for a load of 0.28MN

FEM analysis is carried out for confirmative compressive test specimen from which it is found that the deviation is less than 10%. The analysis work is satisfactory.

IV. CONCLUSION

Taguchi's design of experiments has reduced the experimental work substantially with L9 orthogonal array.

Microstructure studies indicate, there is a uniform distribution of compositions in specimens. After heat treatment and artificial aging Specimen 3 has the highest hardness number and compression strength as a result fine and uniform grain structure.

The specimen No.3 has maximum hardness number and compression strength which is attributed to the fine and uniform grain structure.

Confirmatory test specimens were casted and tested as a part of taguchi method and the results were found satisfactory the deviation were under 10 percent.

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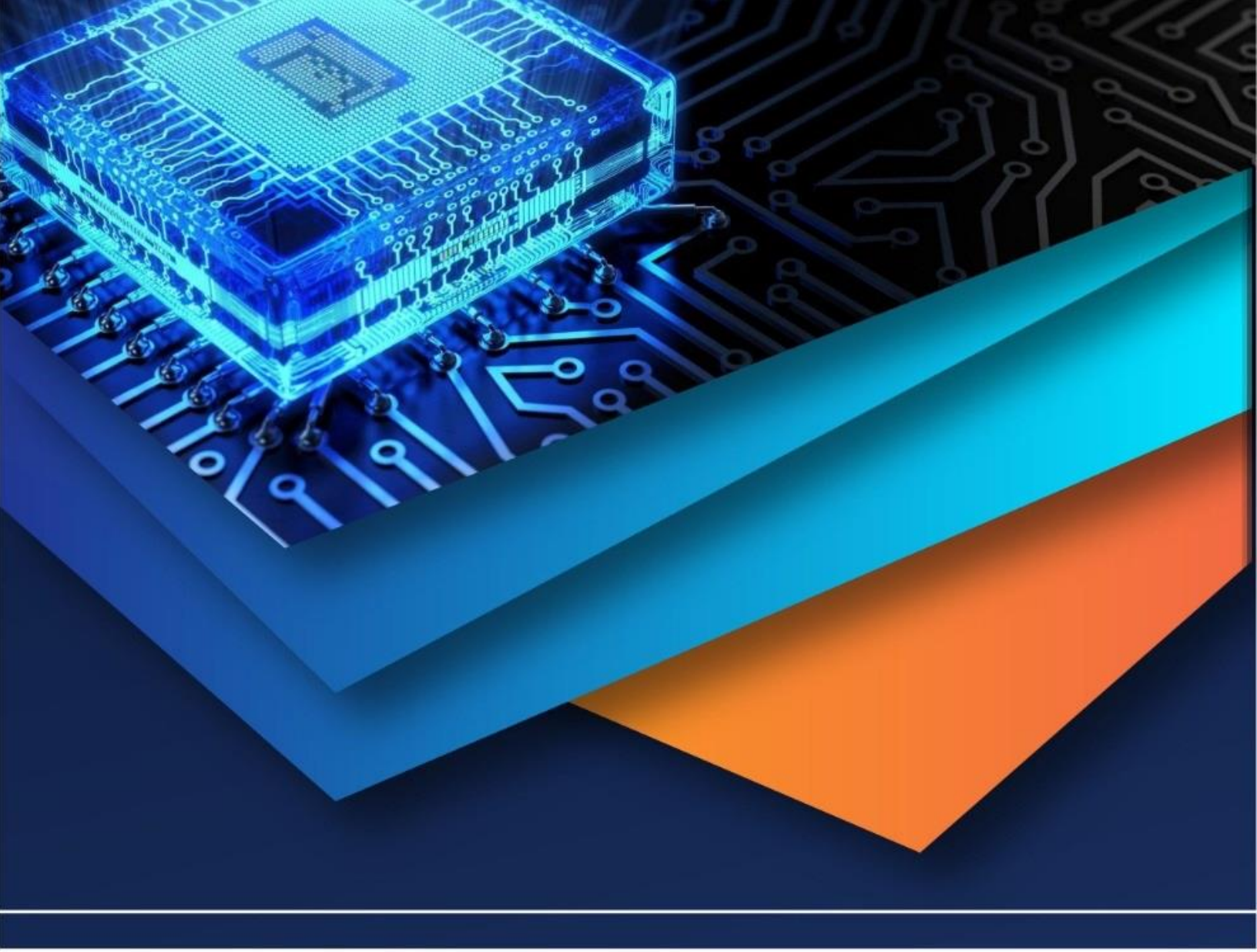

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