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Investigation of Aluminium Oxide Coating on A216 WCB Steel by Plasma Spraying Technique

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Abstract:** Thermally sprayed coating is commonly used to modify the surface of engineering materials to improve the mechanical properties such as hardness, wear resistance and corrosion resistance to meet the functional requirements of the products in industries. Innumerous research works were carried out across the world to assess the suitability of the coating for industrial applications and it is interesting to note that the most of the researchers opted Al2O3 powder for coating the substrate using thermal spray process. In the meantime, few researchers expressed the deterrent effect of decarburization on the coating's mechanical properties due to processing in the thermal spray process at high temperature, which reduces the coating process's performance. Because of the design of the thermal spray process with high velocity oxy-fuel, residual stress building up in thick deposits is a significant and limiting issue. The residual stress-state that evolves in a deposit is largely dependent on the thermal conditions to which the system has been subjected, and is a combination of quenching stresses, which arise during deposition and cooling stresses, post-deposition. It follows that if a thick layer is to be sprayed thermally, precise control of such phenomena is necessary. To overcome this plasma spray technique is employed and tungsten carbide with cobalt is coated on the substrate of material to improve the abrasive wear resistance. In this research work, coating ofAl_2O_3powder over ASTM A216 steel substrate through plasma spray process was considered to investigate the effect of introducing the carburization process on wear properties of the resultant coating. The thickness of layers produced by plasma based ion implantation range from nano to micrometers. Here carburization is introduced on the substrate before plasma spray coating to compensate the loss of carbon during spraying due to this there will be increase in the wear resistance and increase in the efficiency of the steel, so that material hardness takes place in the carburized steel to reduce the wear rate and to increase the wear resistance. The characteristics under abrasive wear conditions are studied for plasma sprayed Chromium carbide Al2O3 coating in comparison to steel. An investigation on the wear behavior before and after the plasma sprayed coating is carried out. The surface of the treated coating is examined by scanning electron microscope, hardness, wear and Corrosion test.
Keywords: Coating, Aluminium oxide, Mechanical properties, Plasma Spray, Corrosion test

I. INTRODUCTION

A. Steel

Steel is an iron alloy and other materials, primarily steel, and is commonly used in building and other applications due to its high tensile strength and low cost. Depending on its temperature, the base metal, iron, will take on two crystalline forms, body centered cubic and face centered cubic. It is the interaction between those allotropes and the alloying elements, primarily carbon, that gives their unique range of properties to steel and cast iron. For the cubic arrangement centered on the body, there is an additional iron atom in the middle of each cube, and in the cube centered on the face, one is in the middle of each of the cube's six faces

B. A216 WCB Steel

The ASTM A216/A2I6 M Valve grade is the most commonly used. Forged ASTM A105 is the cast counterpart of ASTM / A216-WCB. Carbon Steel type A216 is for non-corrosive service applications ranging from -29 ° C (-20 ° F) to 427 ° C (800 ° F) for petrochemicals, coal, water, steam, and general industry. The material has a maximum carbon percentage of 0.35 per cent and falls below the medium carbon steel form. Aluminum oxide being an apt material for corrosion resistance and high mechanical properties is synthesized and used for coating. The coating is made using plasma spray

C. Surface Engineering

Surface engineering can be defined as the branch of science dealing with methods to meet the desired surface requirements and their actions in engineering component service. In hostile settings, engineering elements have to execute those tasks completely and efficiently, under specific conditions.Improving an existing product's performance is just one of the surface engineering goals. New coatings and processes for treatment may also generate markets for new products that would otherwise not exist.

D. Plasma Spray Process

The material to be deposited (feedstock) — usually as a powder, often as a liquid, suspension, or wire — is injected into the plasma stream, emanating from a plasma torch, during plasma spraying phase. In the plane, where the temperature is about 10,000 K, the. Plasma gas flows and gushes across the cathode and shaped as a constricting nozzle. Powder is fed into the plasma flame most commonly via an external powder port mounted near the anode nozzle exit. The powder is so rapidly heated and accelerated that spray distances can be in the order of 25-150 mm

Figure 1.4.1. Plasma spray coating gun.

E. Alumnium Oxide Powder

Aluminum oxide is a ceramic compound found in different chemical compositions: Al_2O_3. It does exist as a gray solid under normal conditions. It is highly durable, and resistant to corrosion. It is also a refractory material, meaning it still maintains its strength at high temperatures. Those properties make it useful as a metal alloys additive.

Aluminium oxide has three different crystal structures which correspond to the three different chemical compositions. Al_2O_3 has a cubic crystal structure, and 976 kg / mm^2 of Vickers hardness. Al_2O_3 is the primary form of aluminium oxide used in surface treatment, for this reason.

Figure 1.5.1. Alumnium oxide powder.

Table 1.1 Powder descriptions.

Chemistry	Al_2O_3
Manufacture	Sintered and Crushed
Morphology	Gray orthorhombic crystals
Purpose	Abrasive wear resistance
Service temperature	<2000C
Apparent density	4.3gm/cc
Process	APS , PLASMA

II. PROBLEM IDENTIFICATION

A. Problem Definition

A216 steel from medium carbon steel is commonly used in heavy industrial applications such as valves and pipe lines joints. The material degradation due to corrosion, however, reduces the material's performance and lifespan. Because of this wear resistance and efficiency low carbon steel has not been successful.

B. Problem Statement

1) Aluminium oxide is applied to the steel before coating with aluminium oxide in order to increase the adhesiveness and hardness.
2) So that material hardening occurs during steel coating to reduce the corrosion rate and improve wear resistance

C. Methodology

Initially the Al_2O_3 coating process is performed using plasma spray coating system on the selected steel. Then we will do the methods below to examine the specimen's mechanical and wear properties.

1) Plasma Spray Coating
2) Scanning Electron Microscope Study
3) Toughness test
4) Corrosion testing

III. EXPERIMENTAL PROCEDURE

A. Material Selection

WCBA216 Medium carbon steel is the most commonly used for oil based applications in valves and pipelines. It is commonly available in square bar, round pin, rectangular bar and steel types such as I-Beams, H-beams, angles, and channels. This grade is selected based on literature survey for the project. The steel appears in Figure 4.1.

Figure 3.1 Medium Carbon Steel

B. Physical Properties

This standard is suitable for carbon steel casts for valves, flanges, fittings or other pressure-containing components for high-temperature service and quality assembly by fusion welding with other casts or wrought-steel components. Steel castings shall be heat treated and furnished in the annealed, or normalized, or standardized and tempered conditions, according to their design and chemical composition, after being allowed to cool below the range of transformation. The surface of the castings of steel shall be free of adhering elements such as sand, holes, hot tears and other discontinuities and, as such, shall be welded in repair when deemed necessary. Lean steel wa physical properties

Table 3.1.1 Physical Properties of low carbon steel

Physical Properties	Metric	Imperial
Density	7.82 g/cm^3	0.275 lb/in^3

C. Mechanical Properties

Mechanical properties of low carbon steel is give in the table 3.1.2

Table 3.1.2. Mechanical Properties of WCB A216 steel.

Mechanical Properties	Metric	Imperial
Tensile Strength, Ultimate	570 MPa	83×10^3 psi
Tensile Strength, Yield	290 MPa	43×10^3 psi
Elongation at Break (in 200 mm)	21.0 %	21.0 %
Elongation at Break (in 50 mm)	25.0 %	25.0 %
Modulus of Elasticity	210 GPa	30×10^6 Psi
Bulk Modulus (typical for steel)	140 GPa	20×10^3 ksi
Poissons Ratio	0.290	0.290
Shear Modulus	79.3 GPa	11500 ksi

The coating deposition on the steel substrate was implement at room temperature, using the following parameters:

Gun	3MB
Nozzle	G4
Argon	100-120 Psi
Hydrogen	50 Psi
Voltage	60-70 volt
Powder Feed	50-60 gram/mint
Spray Distance	3”-6”

D. Coating Procedure

In this processes energy sources are used to heat the powder material which is used to coating in to a molten or semi-molten state and accelerated towards a prepared surface by carrier gases. The coaxial magneto plasma accelerator (CMPA) is used to deposit the Al_2O_3 coating on the medium carbon steel substrate, which has a dimension of 12x12x50mm. The power needed is supplied by an energy storage. This storage is separated into 4 sections of capacitors. The current supply allows varying the level of charge capacity up to 25.8 mF. The maximum voltage charged is 5.0 kV. Thus, a high energy of 360 kJ can be put into the system during one working cycle.

After the accelerated channel is turned off, the plasma flow interacted with the substrate which is located at a distance of 60 mm from the channel edge. When the plasma flow is presented, its speed can reach values of ~3 km/s. It should be noted that the duration of plasma gas impact is lesser than 1 ms in the considered system. When the coating process is finished, the vacuum chamber is open to collect the substrate with the deposited coating.

Steps involved in coating procedure…

1) Cleaning of specimen
2) Parameters are set to the plasma spray process
3) Powders are poured in to the hopper
4) Plasma gun sprays the powder on the substrate to the micron level
5) Coated substrate was allowed to cool in atmosphere for an hour

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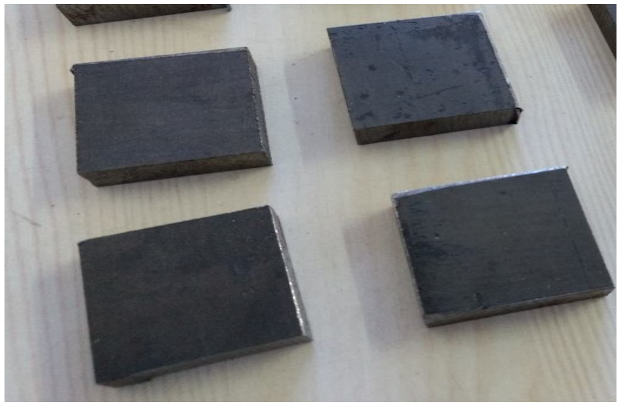

Figure 2.2 Non Coated Steel.

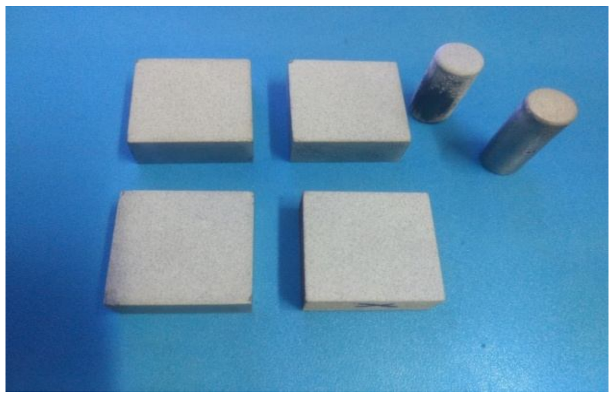

Figure 2.3 Coated Steel.

The coating deposition on the steel substrate was implement at room temperature, using the following parameter

IV. RESULTS AND DISCUSSIONS

In electro chemical work station total three electrodes are used. One is reference electrode, then a counter electrode and the sample to be tested. Reference electrode is AgCl electrode, and counter electrode used is platinum electrode. The third electrode is specimen. Three tests were taken in order to compare the corrosion rate of uncoated and coated samples. Graphs were plotted using the obtained values.

A. Coated Sample - Corrosion Test Result

A graph was plotted using the values obtained from the testing. Graph was plotted between current and potential

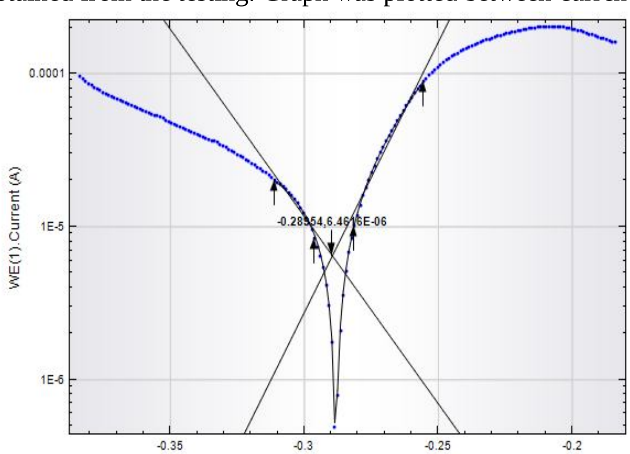

Figure 4.3.1 Corrosion rate graph of coated sample

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Table 4.3.2 Interpretation from graph

ba (V/dec)	0.35627
bc (V/dec)	0.02905
Ecorr, Calc (V)	0.47186
Ecorr, Obs (V)	0.47196
jcorr (A/cm²)	5.49E-06
icorr (A)	5.49E-06
Corrosion rate (mm/year)	0.063805
Polarization resistance (Ω)	1256
E Begin (V)	0.49683
E End (V)	0.44769

B. Uncoated Sample - Corrosion Test Result

A graph was plotted using the values obtained from the testing. Graph was plotted between current and potential

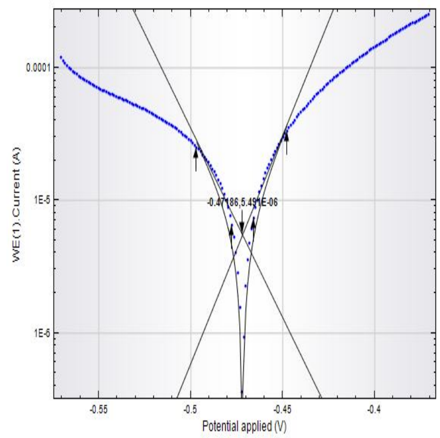

Figure 4.4 Corrosion rate graph of uncoated sample

Table 4.3.3 Interpretation from graph.

ba (V/dec)	0.35627
bc (V/dec)	0.050709
Ecorr, Calc (V)	0.28954
Ecorr, Obs (V)	0.28828
jcorr (A/cm²)	2.48E-05
icorr (A)	2.48E-05
Corrosion rate (mm/year)	1.38849
Polarization resistance (Ω)	776.56
E Begin (V)	0.31113
E End (V)	0.25558

The interpretations from the corrosion test graphs of coated and uncoated samples were compared. Corrosion rate of three samples were studied. It was found that for coated sample shows a corrosion rate of 0.063805mm/year where as corrosion rate of medium carbon steel shows the corrosion rate of 1.38849 mm/year. It was concluded that a micrometer thickness of coating for Al_2O_3can increase corrosion resistance of steel than normal steel.

C. Scanning Electron Microscope Analysis

The aluminium oxide coated sample was studied by Scanning Electron Microscopy. The Scanning Electron Microscopy (SEM) test was conducted on the Aluminium oxide coated specimen with a magnification for 220x ,500x, 1000x,2000, and 3000 are analysed and studied.

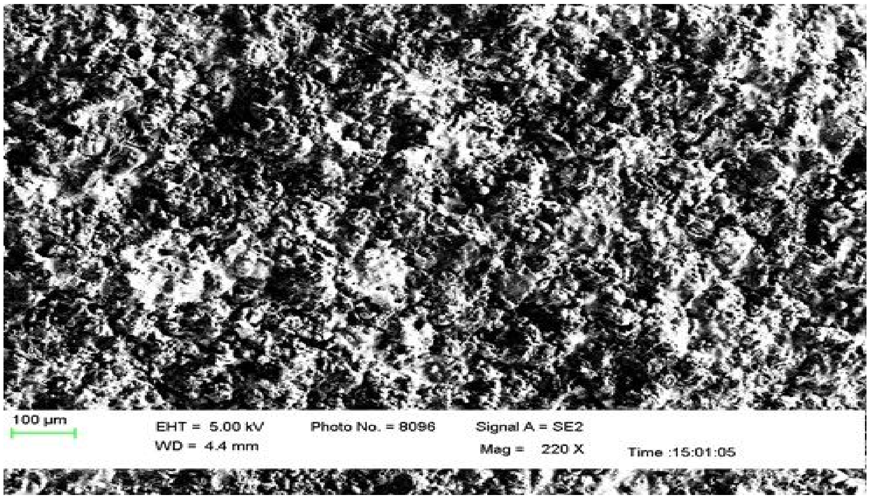

Figure 4.5 SEM image of aluminium oxide coated sample 220x

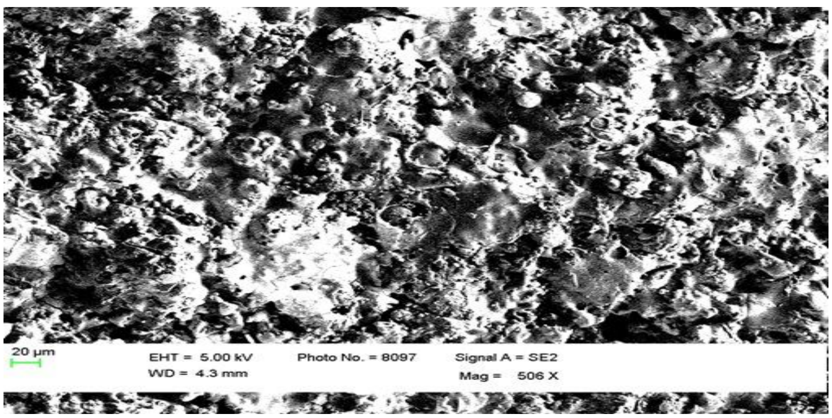

Figure 4.6 SEM image of aluminium oxide coated sample 500x

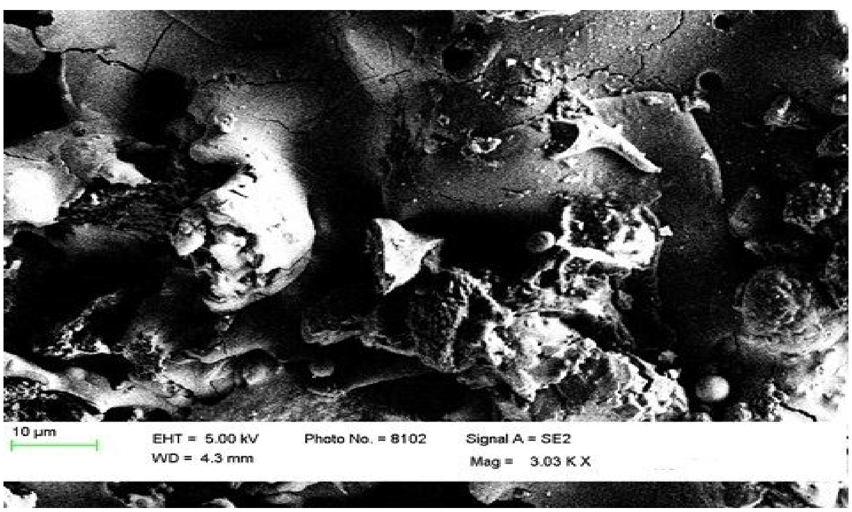

Figure 4.7 SEM image of aluminium oxide coated sample 3000x

The Al_2O_3 particles distribute uniformly in the coating. The sharp irregular shapes of the small Al_2O_3 particles indicate that these Al_2O_3 particles are not molten during spraying. Therefore, it can be assumed that the metal binder is partly or fully melted, where some of the Al_2O_3 particles remained in the solid state during spraying. After the analysis it concluded that coating is uniformly distributed and closely packed.

D. Hardness Examination

Although it is the coating surface that is subjected to the stresses that result in wear, it appears to be almost universal practice in the PLASMA spray industry to perform micro hardness indentation on the polished cross-section. This is due to both the difficulty and costs associated with polishing large areas of very hard material and retaining planarity, and to the requirement that there remain a sufficient coating thickness under the indent for the measurement to be valid. Metallographic cross-sections are usually prepared for optical microscopic examination anyway.

The addition of the Al_2O_3 promoted an increase in the coating hardness. An increase in hardness is achieved. The rockwell hardness value is calculated on the Al_2O_3 coated steel. The value of rockwell hardness on indentation of the coating reading is in Table 4.3

Table 4.3 Rockwell hardness test

S.No.	Type of Steel	Load on indenter (kg)	Diameter of indenter (mm)	HRB
1.	Medium carbon steel	100	2.5	72.2
2.	Al_2O_3 Coated medium carbon steel	100	2.5	92.6

The above table shows the value of Rockwell hardness of the load of 100 N on the indenter that is impressed on the material. The hardness value of the standard specimen is found to be 72.2 HRA. The indenter diameter is 2.5 mm which is applied on the coated material at the load of 92.6 HRA. The impression on the coated material is measured by which the value of the Rockwell hardness and it is determined that the Al_2O_3 coated steel has increased in the hardness value in than other steel.

E. Depth Of Coating

Plasma coating is coated for A2116 with aluminium oxide. Coating thickness is measured by microscopic method. The thickness values are observed for two layer as layer 1 and layer 2.

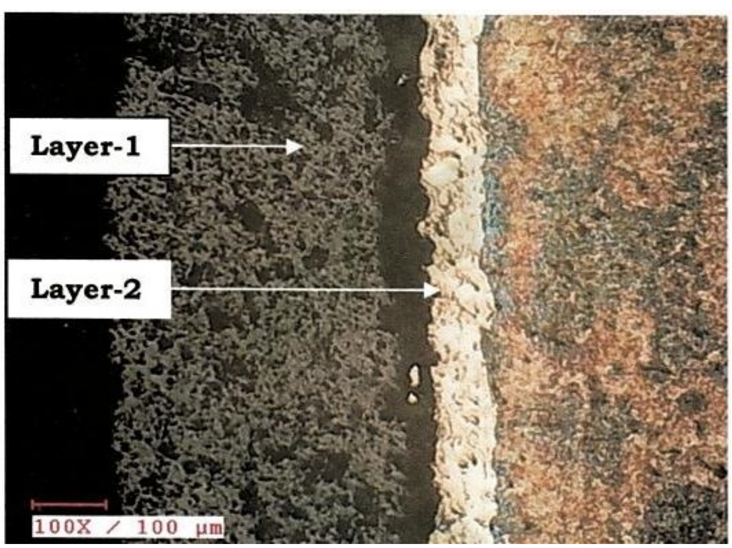

Figure 4.7 Depth of coating

Table 4.4 Coating Thickness values

Layer 1	450	450	460	400	430	Average 438
Layer 2	85	65	90	75	85	Average 80

V. CONCLUSION

The detailed literature survey revealed the existence of a research gap related to addressing of the effects of corrosion of medium carbon steel during high temperature application. The research work conducted under this background with an aim of improving the corrosion properties of the resultant coating through the introduction of high temperature application scope to bridge the research gap. In this research work, coating of on WCB A216 steel through plasma spray process was undertaken for the study of corrosion properties.

A. The corrosion test of coated and uncoated specimen is conducted, it is concluded the uncoated specimen has corrosion rate of 1.38849mm^3/year and the Al_2O_3 coated specimen has a corrosion rate of 0.0630mm^3/year and confirms there is an appreciable corrosion resistance in the aluminum oxide coated area than the uncoated ASTM A216 WCB steel. The increase in corrosion resistance of the base material is due to the aluminum oxide coating formed by the high velocity oxy fuel process.

B. The hardness value of the standard specimen is found to be 72.2 HRB. The indenter diameter is 2.5 mm which is applied on the coated material at the load of 100 N. The impression on the coated material is measured by which the value of the Rockwell hardness and it is determined that the Al_2O_3 coated steel has increased in the hardness value in than other steel. It was also confirmed that hardness of the resultant coating, done on the medium steel was increased (92.6 HRB) remarkably.

C. After the scanning electron microscope analysis it concluded that coating is uniformly distributed and closely packed.

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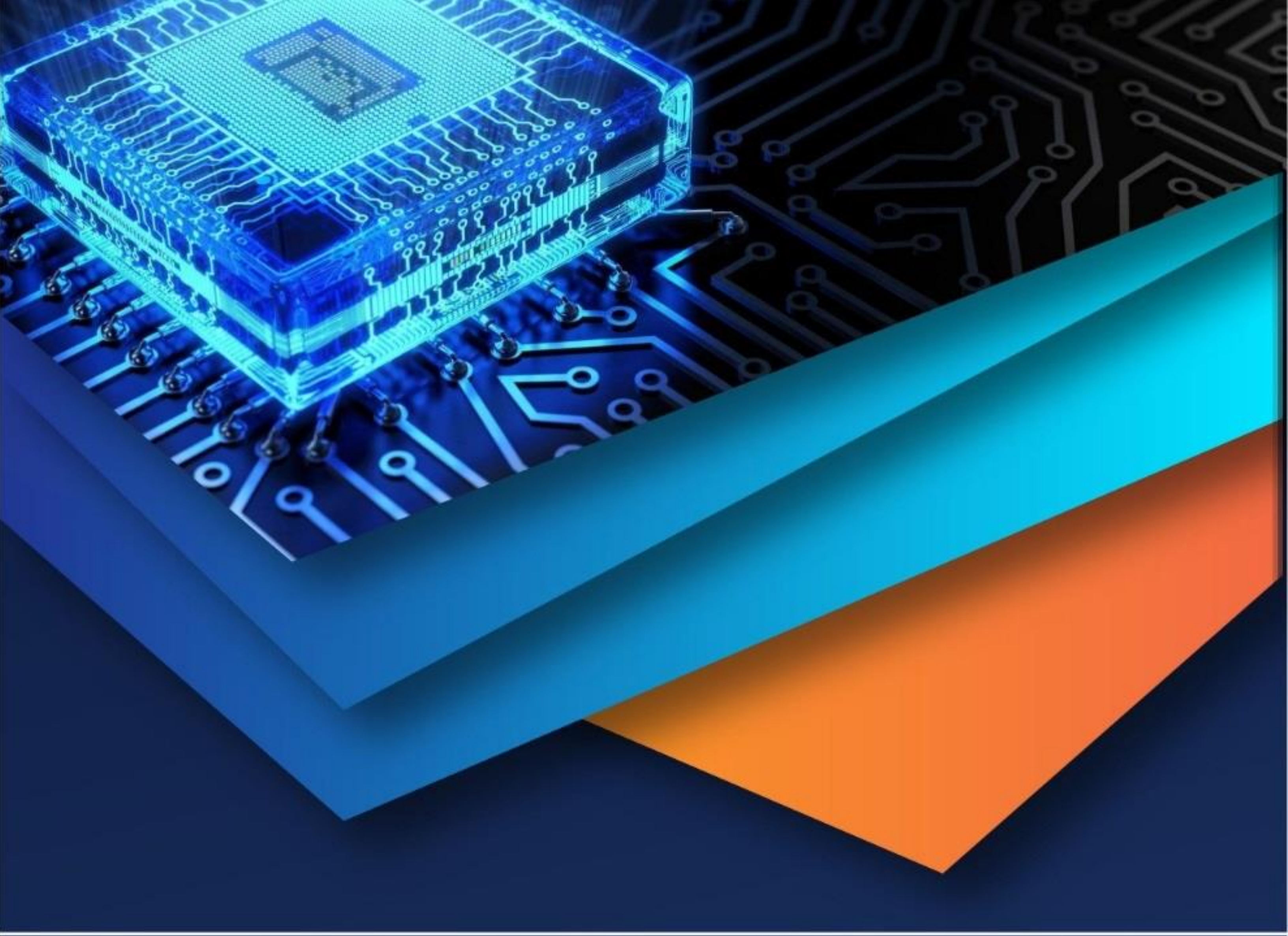

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