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Wear Analysis of Chromium Carbide Coating on A516 WCB Steel by Plasma Spraying Technique

Hariharan. K[1], Jayasurya. B[2], Manoj. K[3], Navin. S[4], Prathap. P[5]
[1, 2, 3, 4]Students, [5]Assistant Professor, Department of Mechanical Engineering, Kathir College of Engineering, Coimbatore

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 Chromium carbide oxide powder for coating the substrate using thermal spray process. In the meantime, few scientists talked about the deterrent effect of decarburization on the mechanical properties of the coating due to thermal spray processing at a high temperature, thereby reducing coating process efficiency. The design of the high speed thermal spray process oxy-fuel causes severe and minimal problems in residual stress in thick deposits. The residual stress state in a deposit depends primarily on the thermal conditions underlying the system and incorporates quenching stresses that occur in the process of deposition and cooling and post-deposition stresses. Therefore, if a thick layer is to be thermally sprayed, it is important to monitor such phenomena accurately. To solve this Plasma Spray Technique, the base of the material is coated with chromium carbide, which increases abrasive usability. In this research project, the effect of applying the carburization process on the wear characteristics of the resulting coating was investigated by coating the chromium carbide powder with the ASTM A516 steel substrate via plasma spray process. The thickness of the ion implantation layers varies from nano to micrometers. This would lead to an improvement in wear resistance and improvement in performance of the steel in order to achieve a material hardship in the carbon-caused steel to minimize wear levels and improve wear resistance before coating to compensate for loss of carbon during spraying. A wearing action review is performed before and after the coating. Depth of the coating, toughness and corrosion checks are carried out on the surface of the treated coating.
Keywords: Spray coating, Plasma Spray, Mechanical Properties, ASTM A516, Hardness, Corrosion resistance.

I. INTRODUCTION

Serviceable engineering components depend not only on the properties of their bulk materials, but also their surface design and features. The behavior of a material is therefore greatly dependent on the surface of a material, surface contact area and the environment under which the material must operate surface engineering a wide range of functional properties can be developed by techniques including physical, chemical, electric, electronic, magnetic, mechanical, wear-resistant and corrosion-resistant properties on the necessary surfaces of the substrata. Almost all materials such as metals and ceramics can be filled with identical or different materials by polymers or composites. Coatings of newer materials, graded deposits, multi-component deposits etc. can also be formed.

A. Steel

Steel has a high strength tensile and low-cost alloy of iron and other materials, primarily carbon. It is used in building and other applications. The base metal, iron, is able to take on two crystalline forms, body centered cubic and face centered cubic depending on its temperature.

The interaction between these allotropes and the alloying elements, primarily carbon, confers its unique properties on steel and cast iron. In the body centered cubic arrangement, there is an additional iron atom in the centre of each cube, and in the face centered cubic, there is one at the each of the six cube faces has its center. Carbon, other elements and iron inclusions serve as hardening agents that prevent dislocation in iron crystallines from moving otherwise. Steels comprise loosely of low-carbon stones (< 0.30%); medium-carbon stones (0.30 -0.60%), intermediate carbon stones (0.60% –0.7%); and heavy-carbon stones (0.60% –1.5%).). These numbers that appear small; they reflect the fact that carbon, while iron, is an atom much larger and heavier, is a small, light element. The existence and especially type of carbide Fe3C is of interest to metallurgists who analyze the detailed structure of steels. The carbon in traditional steel alloys may contribute up to 2.1% of its weight.

Differing the number of alloying components, their presence in steel either as solvent or in precipitated phases, delays the movement and controls its qualities as hardness, ductileity and tensile strength of the resulting steel. Steel's strength is only possible compared to pure iron at the cost of an iron ductility, iron of which is unnecessary. The stain WCBA516 uses common steel grades of 0.30 percent carbon content used under high pressure and operating conditions at temperature. Such materials are moderately resistant to wear, but also susceptible to pitting corrosion that can be used to strip the passivation layer in some regions.

B. A516 WCB Steel.

ASTM A516/A2I6 M is the most widely used valve grade. Forged ASTM A105 is the cast equivalent of ASTM/A516- WCB. A516 type of Carbon Steel is for non corrosive service applications from -29°C (-20°F) to 427°C (800°F) for petrochemicals, gas, water, steam and general industrial applications. This material has a carbon percentage of maximum 0.35 % and falls under the type of medium carbon steel. This type of steel have a considerable corrosion resistance but it is often subjected to pitting corrosion or galvanic type of corrosion and so it is necessary to coat this material with anti corrosive coatings.

In industries to increase wear resistance it is often coated with general paints or is hard faced with other harder materials. But since it is a material used for high temperature-pressure applications it is necessary to select a proper cost effective coating. Chromium carbide being an apt material for corrosion resistance and high mechanical properties is synthesized and used for coating. The coating is made using plasma spray. Chromium carbide possesses a high melting point of 1895°C, low thermal expansion coefficient, thermal shock resistance and wear resistance, therefore it is can be utilized for high temperature applications.

C. Surface Engineering

Surface engineering can be defined as a science division dealing with methods to meet the required surface requirements and their conduct in engineering components' operation. In different conditions and hostile environments, engineering components need to complete and efficiently perform such functions. One goal of surface engineering is to boost the operating capability of an existing product. New coatings and processes may also provide opportunities for new products that would otherwise not be available. For example, without the application of advanced surface engineering techniques, satellites could not work nor could modern power stations operate safely. A technological part usually fails when its surface can not adequately stand up to its external forces or environment. The preference and adequate resistance to wear, corrosion and deterioration of the surface material, which has the required thermal and optical, magnetic and electrical properties. Often only surface requirements will constrain technical advancement and manufacturing performance. For example, gas turbines and diesel engines are limited in terms of fuel efficiency and power output by the ability of key components to withstand high temperatures. However the fact that the processing of components of a bulk material simply for its surface properties is often impractical, costly or unéconomic – it is much easier to use a cheaper, more easily formulated material and cover it with the correct high performance film. The resulting product conserves scarce materials, is better than the original and can be manufactured cheaper.

1) *Plasma Spray Process:* During plasma spraying, a substance (feedstock) is injected into plasma jet that comes from the plasma torch, usually as a powder, often as liquid, suspension or tube. The substance is melted and pushed into a substratum when the temperature in the jet amounts to 10000 K. The molten droplets smooth, solidify easily and form a deposit. Deposits remain commonly adherent as coatings to the substratum, and standing sections are often created by the deletion of the substratum. The interaction between the particles and the plasma jet and substrate is determined by a broad range of technology parameters assets of deposit. The parameters include feedstock form, gas and flow rate of plasma, power supply, offset distance for torch, cooling of substrates, and so onThe Plasma Spray Process is basically to spray material molded or heat-reduced onto a surface to make a coating available. Powder material is pumped into a plasma flame of very high temperatures, where it is easily heated and high speed. The hot substance influences the surface of the substratum and easily cools up to form a layer. This correctly performed plasma spray process is referred to as a "cooling process," as the substratum temperature can be kept low during processing in order to avoid damage, metallurgical changes and distortion. The plasma spray gun includes a copper anode and a water-cooled tungsten cathode. Plasma gas flows around the cathode and through the anode, shaped as a narrowing dust. Powder is most commonly transmitted to the plasma flame through an outside powder port connected to the anode nozzle exit. The powder is heated and accelerated so quickly that spray lengths of 25-150 mm can be reached. Figure 1.1 displayed the plasma spray device.

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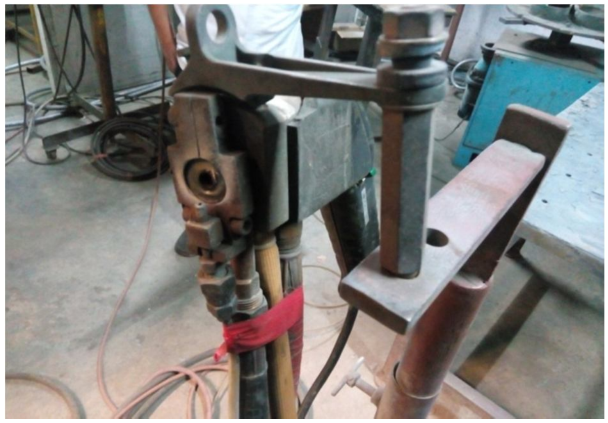

Figure 1.1.Plasma spray coating gun.

D. Chromium Carbide Powder.

Cr3C2, Cr7C3 and Cr23C6 is a pottery compound that is present in a variety of chemicals. It exists as a gray solid under normal conditions. It is extremely hard and corrosion resistant. It is also a refractory compound that retains its strength at high temperatures too. Such characteristics support it as a metal alloy additive. Once chromium carbide crystals have been incorporated into a metal surface, it increases resistance to wear and corrosion and retains these properties at high temperatures. For this purpose, Cr3C2 is the hardest and most commonly used composition. The three different chemical compositions of chromium carbide have three different crystal structures. Cr23C6 has a crystal structure of cubic and a 976 kg / mm2 hardness of Vickers. The hexagonal Cr7C3 structure is 1336 kg / mm2 with a micro-hardness. Cr 3C2 has an orthorhombic crystal structure of 2280 kg / mm2 micro hardness and is the most robust of all three compositions. This is why Cr3C2 is the main chromium carbide element used in surface processing.

Figure 1.2.Chromium carbide powder.

Table 1.1 Powder descriptions.

Chemistry	Cr3C2
Manufacture	Sintered and Crushed
Morphology	Gray orthorhombic crystals
Purpose	Abrasive wear resistance
Service temperature	<2000C
Apparent density	4.3gm/cc
Process	APS , HVOF

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II. EXPERIMENTAL PROCEDURE

A. Material Selection

WCBA516 Medium-carbon steel is used most often in oil-related valves and pipelines. The bar, round rod, rectangular bar, and steel shapes are commonly available in square Bar, I-Beams, H-beams, angles and canals. This degree is based on a literature survey selected for the project. In figure 4.1 the steel has been shown.

Figure 2.1 Medium Carbon Steel

B. Physical Properties

This requirement applies in case of high temperature service carbon steel casts for pipes, fittings or other pressurized parts and of high quality, suitable for assembly by fusion welding with other castors or wrought steel parts. Steel castings are heat treated and fitted in annealed, standardised, normative and tempered conditions, according to their design and chemical composition, after cooling under the transformation line has been permitted. The surface of the casts is free of attachment elements such as sand, cracks, hot tears and other discontinuities and, as such, is sold as required. Physical properties of mild steel was given in the table 4.1.

Table 2.1 Physical Properties of low carbon steel.

Physical Properties	Metric	Imperial
Density	7.82 g/cm3	0.275 lb/in^3

C. Mechanical Properties

Mechanical properties of low carbon steel is give in the table 4.2

Table 2.2.Mechanical Properties of WCB A516 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	20×10^3ksi
Poissons Ratio	0.290	0.290
Shear Modulus	79.3 GPa	11500 ksi

D. Applications Of Medium Carbon Steel

This low carbon stain is used in casts for valves, flanges, fittings or other high temperature service pressurized parts of high quality that are suitable for fusion soldering assembly with other castings or wrought-stone parts. It is used in Fastener, Machinery Fittings Casting base plates, forgings, stakes, brackets, machinery parts. It is used for various Manhole Cover Casting, Marine Fittings Casting ,Pipe Fittings Casting, Cast Iron Pipe Fittings ,Valve Fittings Casting.

E. 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 spraying material is in the form of powder and requires a carrier gas to feed the powdered material into the plasma jet, which is passing between the hot cathode and the cylindrical nozzle-shaped anode.The coaxial magneto plasma accelerator (CMPA) is used to deposit the Cr_3C_2 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. The CMPA consists of a Z-axis pinch accelerator and an external inductive system , which is used to make the electro erosive wear balanced along the length of the acceleration channel. The electro erosive wear occurs due to interaction between the base metal and walls of the accelerating channel. The electrode system is formed by the chromium accelerating channel and the titanium inserted .located at the tip of the central non-magnetic electrode.
The CMPA is seated in the rim of the working chamber. The A516 WCB Steel is seated on the opposite rim, inside of the chamber. The chamber has a appropriate window to record the plasma flow movement by using a high speed camera. The gas system is used to discharge the air from the chamber before filling it with argon. The working cycle starts by operating the button "ON" in working software. An electronic signal from HSC is transmitted to a pulse generator. After that, the electronic pulsation is amplified and closes the power keys in the discharge circuit. The instantaneous release of power by the capacitive storage cause an increasing current and the increasing of the plasma in the plasma formation zone. The current flow channel created an additional forerunner, having a mass of 1.0 g (Cr_3C_2 with the averaged particle size of 32 µm), which makes the direct contact between the electrodes. While increasing the current, the forerunner converted in to the plasma condition and is accelerated by the conductive and inductive electro-dynamic forces. 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

Figure 2.4.A Coated Steel.

Figure 2.4.B Coated Steel.

Figure 2.4.C Coated Steel.

Figure 2.4.D Coated Steel

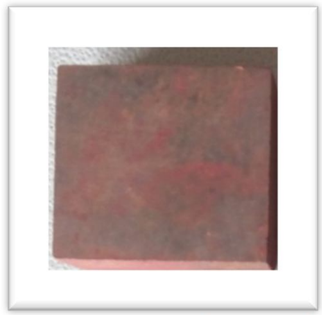


Fig.2.4.E Uncoated Steel

Figure 2.4.F Coated Steel

Fig 2.4.G Uncoated Steel.

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

Table 2.5 Coating 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”

III. PROBLEM IDENTIFICATION

A. Problem Definition

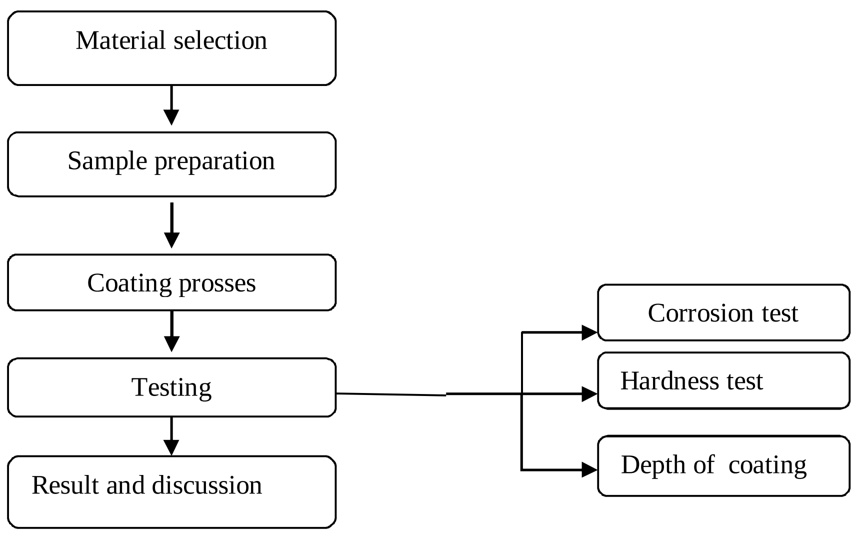
1) Medium carbon steel A516 steel is widely used in heavy industrial applications such as valves and joints of pipe lines.
2) However, the material loss due to corrosion reduces the efficiency and life time of the material.
3) Due to this wear resistance and efficiency are not been effective in the low carbon steel.

B. Problem Statement

1) In order to increase the adhesiveness and hardness of alumium oxide is added to the steel before coating with chromium carbide.
2) So that material harden takes place while coating in steel to reduce thecorrosion rate and to increase the wear resistance.

IV. METHODOLOGY

Initially the Cr_2C_3coating process is performed on the selected steel using plasma spray coating method. Then we should do the following methods to analyze the mechanical and wear properties of the specimen. From the above tests we obtained the results and determined the Cr_2C_3 coated and non-coated mass loss on the steel. Finally we analysed which material is best from the non-coated and coated material. The small specimen material was selected first and analysed the material's chemical composition, mechanical properties and dimensions to suit for the test. Then the type of coating was selected to apply on the specimen through plasma spray coating process. Here Cr_2C_3 powder was selected to coat selected WCBA516 steel and on bare medium carbon steel then to perform plasma spray coating process on the steel to coat the Cr_2C_3 on it. Then series of tests which are mentioned above already are followed.



V. RESULTS AND DISCUSSIONS

A number of experiments on the plasma sprayed substratum were performed, and in the following steps the findings are interpreted. It is clear that when chromium carbide plasma is sprayed on the steel, the mechanical properties are enhanced.

A. Corrosion Test

The salt pulling test is a standardized and common method for corrosion testing material and surface coatings for the purpose of corrosion checking. The products to be tested are typically metallic (although the metal can also be tested for stone, ceramics or polymers) and finished with a surface coating intended to protect the underlying metal from corrosion. Salt spray testing is an accelerated method to carry out corrosiveness on coated research samples so that the suitability of the cover to be used as a protective finish is (mainly comparatively) measured. The presence of corrosion products (rust or other oxides) is measured during a fixed time span. Duration of the test depends on the resistance to corrosion of the coating; usually the longer the time for testing until the start of corrosion / rust the more corrosion resistant the coating. One of the most successful and long-term corrosion tests is the salt spray test. ASTM B117, which was originally published in 1939, was the first internationally accepted salt spraying standard. ISO9227, JIS Z 2371 and ASTM G85 are other relevant standards.

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B. Corrosion Test Parameters

Table 4.2Corrosion test Parameters

SALT SPRAY TEST AS PER ASTM B117-19			
SL.NO	TEST CONDITION	REQUIREMENTS	ACTUAL
1	Chamber Temperature	35+2^{o}C	34.3 – 35.6^{o}C
2	pH of solution	6.5 to 7.2	6.3
3	Air Pressure	12 to 18psi	15psi
4	Concentration of sodium chloride	5%	5.0%
5	Collection of solution Per Hour	1 to 2 ml	1.2 ml
	Test Hours	24hrs	24hrs

C. Corrosion Test Samples

Fig 4.3 Corrosion test samples

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 Cr_3C_2 promoted an increase in the coating hardness. An increase in hardness is achieved. The rockwell hardness value is calculated on the Cr_3C_2coated steel. The value of rockwell hardness on indentation of the coating reading is in Table 5.5

Table 4.4 Rockwell hardness test

S.No.	Type of Steel	Load on indenter (kg)	Diameter of indenter (mm)	HRA
1.	Medium carbon steel	100	2.5	72.2
2.	Cr_3C_2 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 chromium carbide coated steel has increased in the hardness value in than other steel.

E. Coating Thickness

Metallurgical microscopes are sometimes called material microscopes, and can be seen as upright (shown above), inverted metallurgical microscopes (picture on the right), or on a boom, for the viewing of extra large samples. Metallurgical microscopes Upright metallurgical microscopes are being used for viewing microscope suitable samples. A metallurgic inverted microscope can be used to look at wider areas, as the target lenses are under the stage and allow heavy mechanical parts to be mounted directly above the lenses. With a little more working distance, a metallurgical Microscope is needed for a boom stand than a straight metallurgical Microscope. Metallurgical microscopes may look similar in a number of ways to compound biological microscopes. The user can view samples with high magnification (up to 500x and 1000x) using a metallurgical microscope without the use of a light to display a biological sample. Another option when reflected lighting is needed are stereo microscopes, but metallurgical microscopes give a much higher resolution (and magnification) than a stereo microscope.

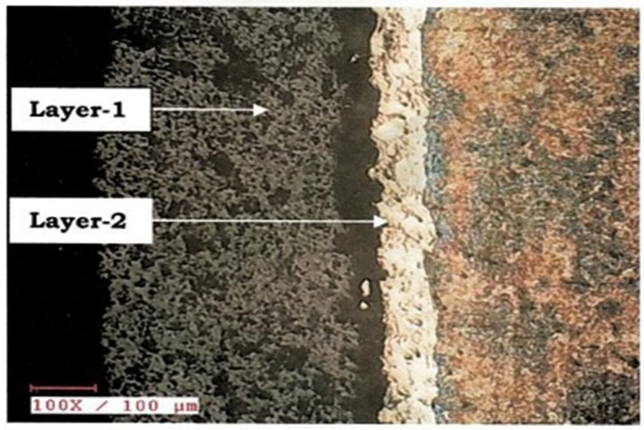

Figure 4.5 Coating Thickness

VI. 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 A516 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 has confirms there is an appreciable red spot in corrosion area in the chromium carbide coated area in ASTM A516 WCB steel. The increase in corrosion resistance of the base material is due to the chromium carbide coating formed by the plasma spraying process.

B. 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 100 N. The impression on the coated material is measured by which the value of the Rockwell hardness and it is determined that the chromium carbide 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 (96.2HRA) remarkably.

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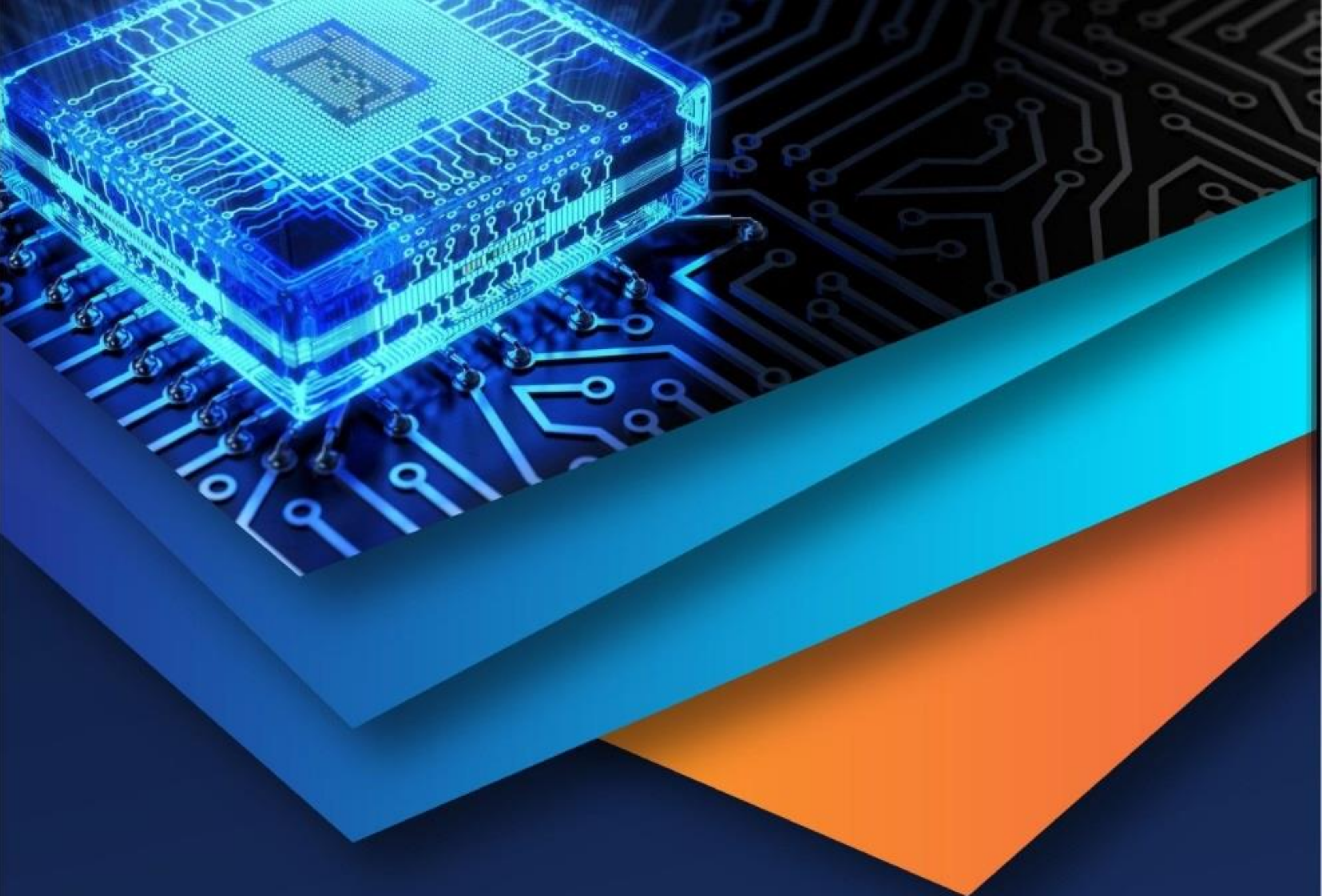

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