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Reducing Thermal Conductivity of (2014-T6&6061) Aluminium alloy using Nickel coating by Electro Deposition method

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Abstract: Nickel coating are employed over the (2014-T6&6061) aluminum alloy to protect it from thermal cyclic load and to improve the performance. Nickel is coated on the aluminum alloy by electro deposition method. This paper deals with conductive heat transfer behavior and hardness behavior of nickel coated aluminum alloy. Hardness behavior and thermal conductivity was determined by brinell hardness testing and specially designed experimental setup respectively.A temperature reduction of nearly 10-14% was observed in aluminium alloy 2014-T6 whereas 12-16% temperature reduction was noticed in aluminium alloy 6061. A hardness increment of nearly 3-7% was observed in aluminium alloy 2014-T6 whereas 11-16% hardness increment was noticed in aluminium alloy 6061. By the nickel coating, thermal conductivity was reduced and the hardness was increased.
Keywords: Electro deposition, Nickel coating, Thermal conductivity

I. INTRODUCTION

Aluminium alloy are used in various domestic application and engineering application. Aluminium alloy is also used as a piston material. When the piston is to high temperature, its property will change. So, it is essential to protect it from high thermal load, and hence thermal barrier coating are to be effected to improve its performance and life.More than half of the energy produced in combustion chamber is expelled through friction losses, exhaust, cooling etc. and very few amount of energy produced is actually converted to useful work. The transfer of heat is conducted through various combustion chamber elements like valves, piston surfaces, rings etc. If this heat loss, however, is reduced to some extent it would have a significant effect on thermal efficiency of engine. One of the necessary requirements with piston material is its high thermal shock resistance. Aluminium alloy is a high thermal conductivity of around 150 W/m K, high heat loss will occur in IC engines. This high thermal conductivity material enhanced the problem the heat loss. This suggested an idea to make use of some suitable coating material over the piston and of course, on the other parts of the combustion zone. The aim of such coating is to provide thermal insulation and oxidation resistance at high temperatures. The major promises of thermal barrier coated were increased the thermal efficiency and elimination of the cooling system

II. LITERATURE SURVEY

Nickel tungsten is coated on the cast iron to improve its properties and their performance. This paper deals about the conductive heat transfer behaviour of cast iron[1]. The objective of the current work was to study in detail the effect of bath chemistry, additives and operating conditions on the chemicalcomposition, microstructure and properties of Ni–W alloys deposited from citrate-containing baths, in the absence of ammonia or ammonium salts, on stationary working electrodes. The morphology of the deposits was studied by scanning electron microscopy (SEM) as well as atomic force microscopy (AFM), and the approximate composition by energy dispersive spectroscopy (EDS)[2].

The code position of micro particles within an electroplating process is a capable method to produce such improved materials. The particles are used to perform specific mechanical, electrical, piezoelectric or magnetic properties in thin coatings. The aim of giving a coating to a substrate is to improve some of its properties of the substrate or to obtain an entirely new property. The composite coating technology is used many manufacturing areas. Composites are multifunctional materials having unprecedented mechanical and physical properties that can be customized to meet the necessities of a particular application. Modern technology aims for systems performing satisfactorily under extreme operating conditions[3].Ni-Fe-W alloys were produced by electrode position from an ammoniacal citrate bath having nickel sulphate, ferric sulphate and sodium tungstate as sources of nickel, iron and tungsten, respectively. The alloys prepared at low current densities have Nano crystalline structure, while those prepared at high current densities are amorphous[4].The depletion of fossil fuel resources at a faster rate in the present world of economic competitiveness is generating an essential demand for increase in efficiency of internal combustion engines. The use of coating in the automotive industry has been found to yield a significant effect on the efficiency of engines. Higher the operating temperature more will be the efficiency of the system. However, such higher temperatures demand for enhanced

temperature resistant materials to be used. This paper presents a review on the application of coating of various thermal insulating materials (commonly known as thermal barrier coatings) over the high temperature components[5]. Composite coatings can be produced by electro-deposition of metals accompanied with no metallic powders such as carbide, oxide or organic compounds to obtained coatings with high wear-resistance, anti-friction or anti-corrosion[6].

The improvements in engine materials are forced by using alternative fuels and environmental requirements. Therefore, the performances of engine materials become increasingly important. The purpose of PZT loaded cyanate modified epoxy system (60EPCY 20PI) is to focus on developing binder systems with low thermal conductivity and improve the coating durability under high load condition. The coating material is made up of 20% Lead Zirconate Titanate (PZT) in 60% Cyanate modified Epoxy system. The triazine ring of cyanate ester offers better thermal resistance characteristics to the epoxy system[7]. Ni-Al2O3 composite coatings were prepared from watts bath through conventional type and sediment type deposition. L9 orthogonal array experimental design was implemented for experimental design. The plating parameters, current density, temperature of bath and particle concentrations were considered with three levels for both conventional and sediment type depositions[8]. The focus of this study is the amorphous and crystalline phase formation in air plasma sprayed alumina–yttria stabilized zirconia coatings. In this multi-component system at compositions close to its eutectic, amorphous structures can arise by virtue of the high cooling rates of melted particles. Two avenues for amorphous phase formation have been identified: in-flight and upon-impact mixing. While the crystalline structure is largely retained by unmelted or partly melted feed particles embedded in the coating, it can also be created in the solidification process[9].The efficiency of internal combustion diesel engines changes %3842. It is about %60 of the fuel energy dismissed from combustion chamber. To save energy, combustion chamber component are coated with low thermal conduction materials. In this paper, give an eye to thermal barrier coating and ceramic materials which are used for making low heat released engines[10].

III. COATING TECHNIQUES

There are several methods used for surface modification of materials. The following techniques are few of them used for applying coatings on metals.

1) Electroplating - Electroplating is a process of coating, deposition on a cathode part immersed into a electrolyte solution, where the anode is made of the depositing material, which is dissolved into the solution in form of the metal ions, traveling through the solution and depositing on the cathode surface. 2) Electroless Plating - The process of deposition of metal ions from electrolyte solution on to the substrate. When no electric current is involved and the plating is a result of chemical reactions occurring on the surface on the substrate.3) Conversion Coating - The process, in which the coating formed as a result of chemical or electrochemical reaction on the substrate. This are non-metallic coating obtained on metal surface in the form of compounds of the substrate metals.4)Hot Dipping - Immersing the part in to a molten metal followed by removal of the substrate from the metal bath, Which results in formation of the metal coating substrate surface.5) Physical Vapour Deposition - The process involving vaporization of the coating material in vacuum, transportation of the vapour to the substrate and condensation of the vapour on the substrate surface.6) Chemical Vapour Deposition - The process, in which the coating is formed on the hot substrate surface placed in an atmosphere of a mixture of gases, as a result of chemical reaction or decomposition of the gases on the substrate material.7) Thermal Spraying - Deposition of the atomized at high temperature metal, delivered to the substrate surface in a high velocity gas stream. We have selected electro deposition technique because it is a conventional techniques, but it is used vastly due to its certain advantages over other as it is low cost, low energy requirement, capability to handle complex geometry, simple scale - up with easily maintain equipment, good chemical stability, easily maintained equipment and after all very important potential of it is every large number of pure metals, alloys, composites, ceramics, which can be electrodeposited with grain size less than 100nm.

IV. SELECTION OF MATERIALS FOR COATING

The material for coating must have a low thermal conductivity value. Since, nickel is a low thermal conductivity of 70 W/m K compared to aluminium alloy.Nickel coating shows the properties of good mechanical properties, excellent corrosion resistance, low thermal conductivity and good magnetic properties. Aluminium alloy 2014-T6 and aluminium alloy 6061are selected as a specimen.

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V. ELECTRO DEPOSITION COATING

Electro Deposition Coating is also a process of applying a layer to the substrate surface. Coating material is different from the substrate material and it permits achieving special surface properties of the part without changing its bulk properties. A aluminium alloy (2014-T6 & 6061) of dimension (5 inch *5 inch *0.25 inch) is used as a specimen.

A. *Components of electro deposition process:*

1) *Electrolyte:* The electrolyte or bath provides the ions to be electrodeposited. It has to be electrically conductive, it can be aqueous, non-aqueous or molten; and it must contain suitable metal salts. Sometimes an additive is included to improve the quality of the electrodeposits. An ideal additive should not become incorporated in the film but should lead to improvement of its adhesion, surface finish, uniformity etc.

The plating solution used was a mixture of:

Nickel Sulfate Hexahydrate (300 g/L),
Boric Acid (45 g/L)
Nickel Chloride Hexahydrate (45 g/L)

2) *Electrodes:* There are two electrodes (cathode and anode) needed for electro deposition. An applied electric field across these electrodes provides the main driving force for the ions. The positive and negative ions deposit at the cathode and anode respectively. Cathodic deposition is more popular in electroplating because (1) most metal ions are positive ions and (2) anodic deposition has been found to give poor stoichiometry and adhesion.
3) *Power Supply:* A DC power source is required to operate any plating
4) *Electrode position process:* The electrodeposition process essentially involves passing an electric current between two electrodes immersed in an electrolyte. The positively charged electrode is known as the anode while the negatively charged electrode is the cathode. The electrolyte contains electrically charged particles or ions. When an electrical potential or voltage is applied between the electrodes these ions migrate towards the electrode with the opposite charge – positively charged ions to the cathode and negatively charged ions to the anode. This results in the transfer of electrons that is a current flow, between the electrodes – thus completing the electrical circuit. The electrical energy is supplied by a DC power source such as a rectifier. The basic electrical circuit is depicted as shown below

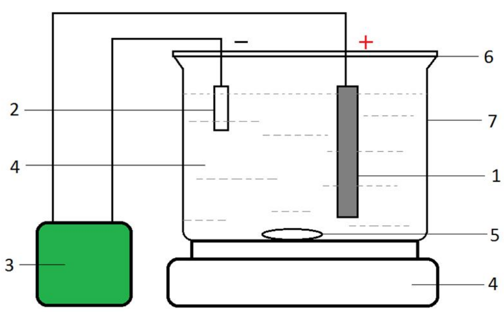

Figure (1)

a) coated material
b) specimen
c) power supply
d) hot plate stirrer
e) stirring bar
f) locating plate
g) beaker
h) electrolyte

Generally in electroplating, the anodes are composed of the metal being plated. These are referred to as 'soluble' anodes. During electroplating, the positively charged metal ions discharge at the cathode (the component to be plated) depositing metal on the surface. The component being plated therefore receives a coating of metal. The reverse effect occurs at the anode and, with a soluble

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anode, metal ions are formed through dissolution. For nickel plating, the electrolyte contains soluble nickel salts along with other constituents which will be discussed in the section on 'Chemistry of Nickel Plating Solutions.' When dissolved, the nickel salts dissociate into divalent, positively charged nickel ions (Ni++) along with negatively charged ions. When current flows, the positive ions react with two electrons and are converted to metallic nickel at the cathode surface. At the anode, metallic nickel is dissolved to form divalent, positively charged ions which enter the solution. The nickel ions discharged at the cathode are thus replenished by those formed at the anode.

Buffing: "Buffing" is the process used to shine metal, wood, or composites using a cloth wheel impregnated with cutting compounds or rouges. The cloth buff "holds" or "carries" the compound, while the compound does the cutting.
Buffing generally requires two operations, a cut buff and a finish buff. Even the cut buff, which is the coarsest buffing operation, is too fine for removal of pits, course abrasive polishing lines, or deep scratches. This is why surface preparation prior to buffing is critical to a high luster, final finish.

Excellent pre-buff surface preparation starts with using the finest abrasive belt that production will allow. It is from this point that removal of the original scratch line needs to be accomplished to achieve the final buff finish.

The original "scratch" or polish is followed by one or two additional polishing steps. Cross polishing the abrasive lines if possible and buff off of approximately 400 grit or finer abrasive on metals.

The cut buff will remove the final polishing lines, but may not be as bright as required. The finishing buff will produce the luster.

Rate of deposition: The amount of metal deposited at the cathode and the amount dissolved at the anode are directly proportional to the quantity of electricity passed – in other words to the current and time of electrodeposition.

V. NICKEL ELECTROPLATING

In nickel electroplating method, nickel plate is used as anode and the material which we have plated used as cathode i.e. negatively charged with the D.C supply. The direct current to the anode is oxidizing the metal atoms and allows them to dissolve in the solution. The dissolved nickel irons in the electrolyte solution traveling through the solution and get deposited on the cathode. The rate of at which the anode is dissolved is equal to the rate at which the cathode is plated, vice-versa the current following through the circuit.

The following solutions are used for nickel electroplating:

Watts nickel plating solutions
Nickel sulfamate solutions
All- Chloride solutions
All- Sulphate solutions

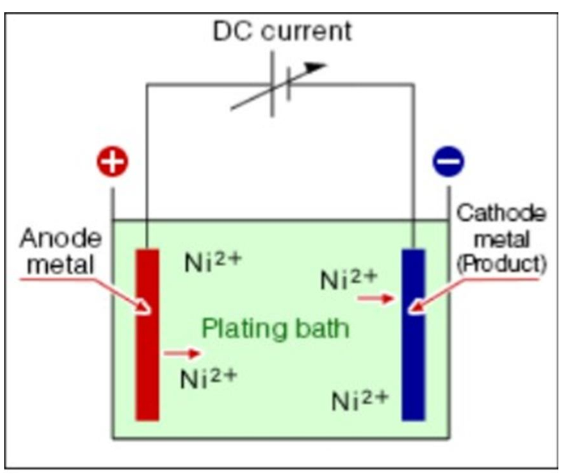

Figure (2)

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Watts's solutions was developed by Oliver P. Watts in 1916 and it is most popular nickel electroplating solution. Plating operation in watts solutions is low cost and simple

VI. THERMAL CONDUCTIVITY TEST

Thermal conductivity is the ability of the substance to conduct heat. The quantity of heat transmitted through a unit thickness of material in a direction normal to a surface of unit area due to a unit temperature gradient under steady state condition

$Q = K A (\Delta T/L)$

The following designed experiment setup and its essential features help to measure the heat transfer behaviour of coating. In the experimental study, conductive behaviour of the electro deposited nickel coating on the aluminium alloy specimen was studied with and without coating. The aluminium alloy is placed on the heating element. An induction stove is used as a heating element because it can control the temperature and the power. As perfect insulation are made all around the surfaces of the source element except the horizontal surfaces by very good insulation material which create an air tight contact between all the vertical faces. After reaching the steady state condition, no temperature gradients were experienced in the x and z direction which ensures one dimensional heat flow. A one-dimensional fourier heat conduction equation without heat generation was assumed for this experiment. Thermocouples are fixed at the top surface of the specimen. The thermocouple connected to a data logger to record the temperature of the top surfaces.

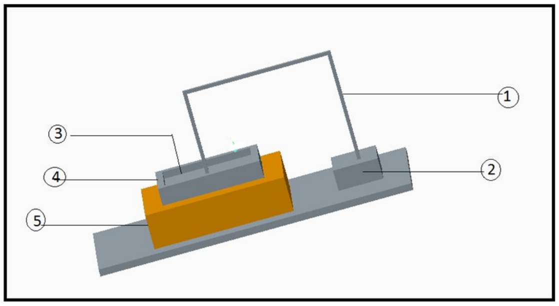

Figure (3)

A. Thermocouple
B. Display indicator
C. Specimen
D. Insulation
E. Heating element

VII. HARDNESS TEST

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting.The Brinell hardness test method as used to determine Brinell hardness, is defined in ASTM E10.The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured across at least two diameters – usually at right angles to each other and these result averaged (d). A Brinell hardness result measures the permanent width of indentation produced by a carbide indenter applied to a test specimen at a given load, for a given length of time. Typically, an indentation is made with a Brinell hardness testing machine and then measured for indentation diameter in a second step with a specially designed Brinell microscope or optical system. The resulting measurement is converted to a Brinell value using the brinell formula or a conversion chart based on the formula. Most typically, a Brinell test will use 3000 kgf load with a 10mm ball. If the sample material is aluminium, the test is most frequently performed with a 500 kgf load and 10mm ball. Brinell test loads can range from 3000 kgf down to 1 kgf. Ball indenter diameters can range from 10mm to 1mm. Generally, the lower loads and ball diameters are used for convenience in “combination” testers, like Rockwell units, that have a small load capacity. The test standard specifies a time of 10 to 15 seconds, although shorter times can be used if it is known that the shorter time does not affect the result. There are other conditions that must be met for testing on a round specimen, spacing of indentations, minimum thickness of test specimens, etc.

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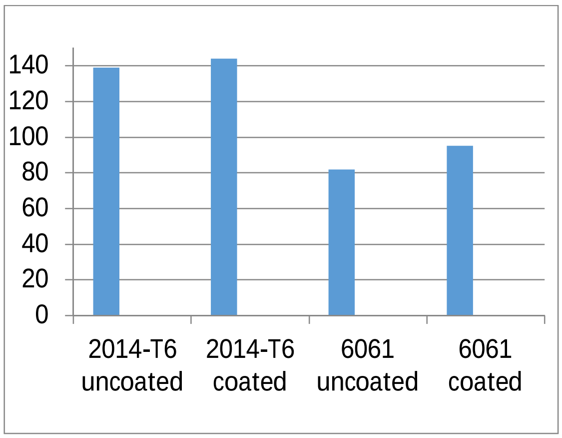
FORMULA

Brinell hardness number = $2P/(\pi D - (D(D^2-d^2)^{1/2})$

VIII. RESULT AND DISCUSSION

In the experimental studies, the aluminium alloy (2014 & 6061) with and without nickel coating were placed over the heating element, the temperature of the outer surfaces were recorded. The thermocouple are used to record the temperature. A known input energy is given to the specimen, and after 60 sec the outer temperature must be measured. This experiment is conducted for both specimen with and without coating. By the experimental analysis, a temperature reduction of nearly 10-14% was observed in aluminium alloy 2014-T6 whereas 12-16% temperature reduction was noticed in aluminium alloy 6061. Both these reduction were observed in 15µm thick coated panel

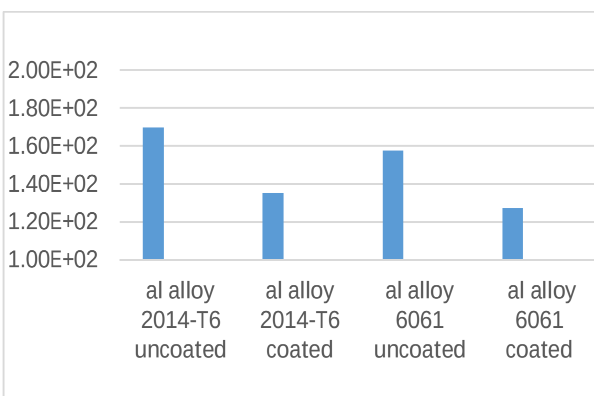
In the hardness analysis, the aluminium alloy (2014 & 6061) with and without nickel coating were conducted a brinell hardness testing. A specimen is placed on the testing machine after that load is applied on the specimen by the carbide balland kept the load for 30 sec and then remove the load. Measure the indentation diameter with a microscope or optical system. The resulting measurement is converted to a Brinell value using the Brinell formula or a conversion chart based on the formula.A chart is then used to convert the averaged diameter measurement to a Brinell hardness number. This experiment is conducted for both specimen with and without coating. By the experimental analysis. A hardness increment of nearly 3-7% was observed in aluminium alloy 2014-T6 whereas 11-16% hardness increment was noticed in aluminium alloy 6061.Both these increment were observed in 15µm thick coated panel



Graph for hardness

A. *Analytical report*

The analytical report shows the thermal conductivity of aluminium alloy (6061&2014-T6) with coated and uncoated. In analytical report, a temperature reduction of nearly 14-18% was observed in aluminium alloy 2014-T6 whereas 13-18% temperature reduction was noticed in aluminium alloy 6061



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B. Graph for thermal conductivity

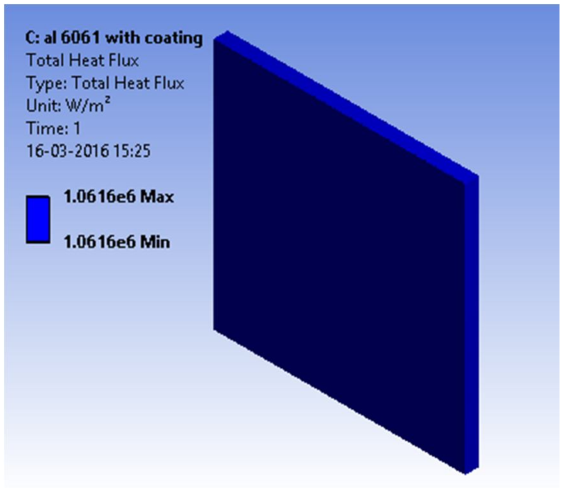

Figure (4)

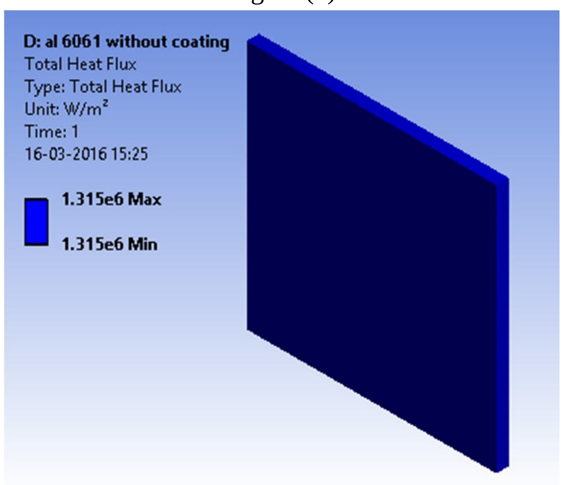

Figure (5)

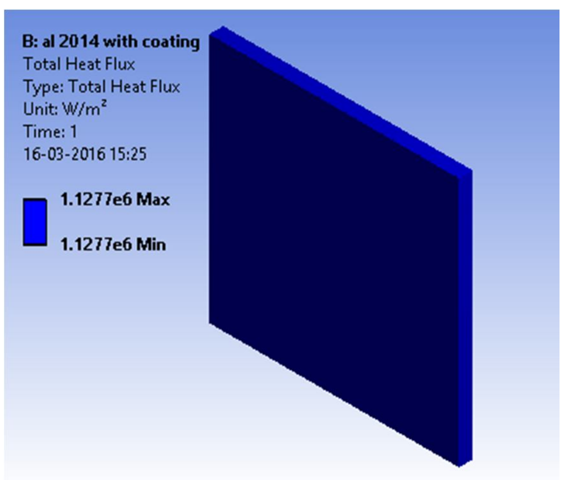

Figure (6)

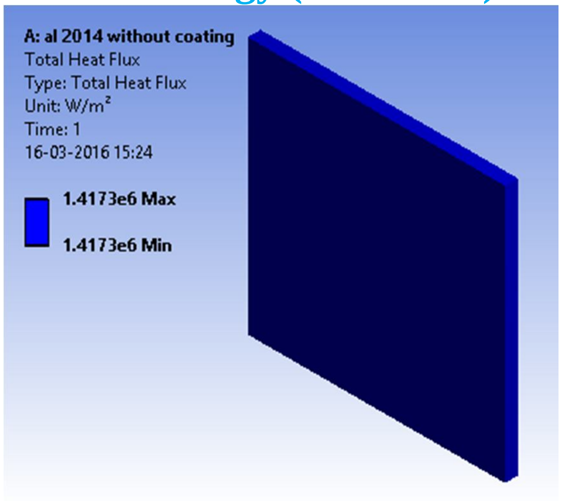

Figure (7)

IX. CONCLUSION

The important conclusion drawn from the present work are given in this section. This work demonstrated the conductive heat transfer behaviour and the hardness behaviour of the electro deposited nickel coating of 15µm on the aluminium alloy(6061&2014-T6). The result clearly showed that the temperature distribution was a function of coating thickness.A temperature reduction of nearly 10-14% was observed in aluminium alloy 2014-T6 whereas 12-16% temperature reduction was noticed in aluminium alloy 6061.A hardness increment of nearly 3-7% was observed in aluminium alloy 2014-T6 whereas 11-16% hardness increment was noticed in aluminium alloy 6061.

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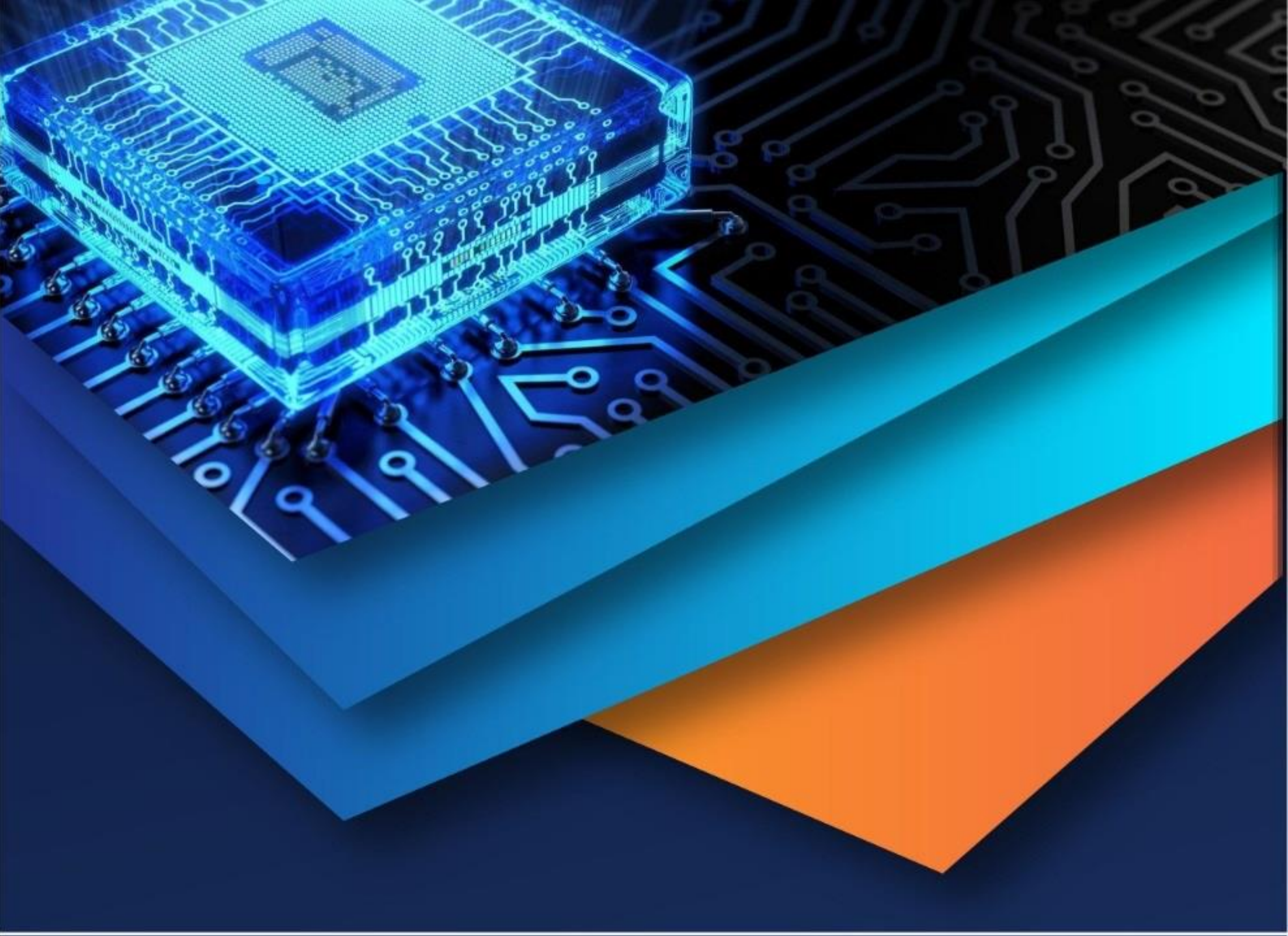

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