iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** IV **Month of publication:** April 2019

DOI: https://doi.org/10.22214/ijraset.2019.4633

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 7 Issue IV, Apr 2019- Available at www.ijraset.com

Analysis of Multilayered Composite Pipe under Internal Pressure using Finite Element Methodology

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Abstract: The influence of an internal pressure on the integrity of multilayered composite pipe is studied in this paper. The multilayer pipe is modeled as a particular case of bi-material body consisting of one main metal layer and two protective layers. The multilayered composite pipelines have advantages of both metal and plastic, such as good strength of metal and light weight of plastic are observed. Metal pipes are destroyed by corrosion failure and plastic pipes are destroyed by brittle-like failure. To prevent this type of pipe damage use of alternative multilayered composite pipe is suggested. This paper includes analysis of the stress, strain distribution and total deformation of the multilayered composite pipe under internal pressure using finite element methodology.

Keywords: Multilayered composite pipe, Internal pressure, Protective layers, PE-AL-PE pipe, Finite element analysis

I. INTRODUCTION

The important mechanical properties of a composite pipe are strength, stiffness and service life, which make it imperative to determine leakage integrity and reliability of a piping system. Multilayered composite pipes have many potential advantages over pipes made from conventional materials, such as high specific stiffness and strength, good corrosion resistance, light weight and good thermal properties. Composites offer many cost advantages over metals due to a considerably higher strength to weight ratio. For example, an increase in the ease of handling decreases the amount of manpower and size of equipment needed for construction and installation [6].

Plastic pipes are nowadays frequently used for the transportation of liquids and gases from one place to another. A diverse range of plastic pipes has been developed to meet the demands of end users. The prevention of their failure is of great practical significance. To guarantee the longer lifetime of pipe systems composite pipes consisting of many layers are employed in practice. These are of cardinal importance, especially in connection with trenchless installation techniques [14]. Homogeneous (one-layer) pipes can be destroyed by cracks initiated at the surface and propagating through the pipe wall. This type of pipe failure is frequent. In many cases, plastic pipes are then cracked in a brittle-like manner. To prevent this type of pipe damage multi-layered composite pipes are used. The development of multilayered composite pipes is connected with new technologies which have not yet been able to be employed in laying new tubes and sanitation. Multi-layered composite pipes can consist of many layers, with different functions and manufacturing facilities must be designed specifically for the various pipe structures. Due to its practical importance the multi-layered composite pipes are studied from a different point of view [1].

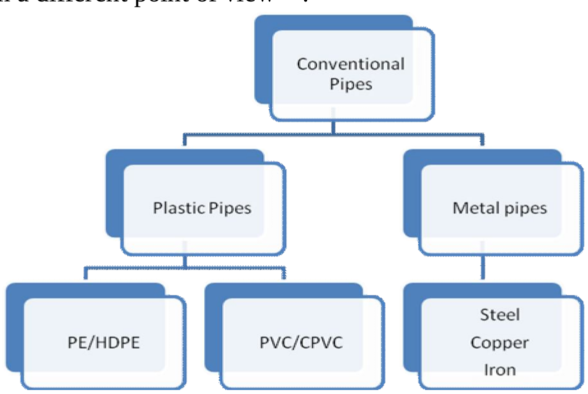

Chart 1 - Types of the conventional pipes used for the transportation of liquids and gases for the low pressure system

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A. Multilayered composite pipe system

Basically, multilayered composite pipes are composed of one main layer (the functional pipe) and a few protective layers as shown in fig.1. The single layers are normally tightly bonded to each other. In the case of poor handling and/or faulty installation of pipes, small cracks or flaws can be created at the surfaces of a pipe and propagated through the pipe body. Other possible causes of crack initiation are connected with stress enhancers and stress concentration. The essential function of the protective layers is to prevent damage to the main pipe caused by surface cracks [14]. To achieve this, the material for protective layers should be chosen properly; in particular, it has to have greater resistance against surface scratching. Polymeric materials show such property [1].

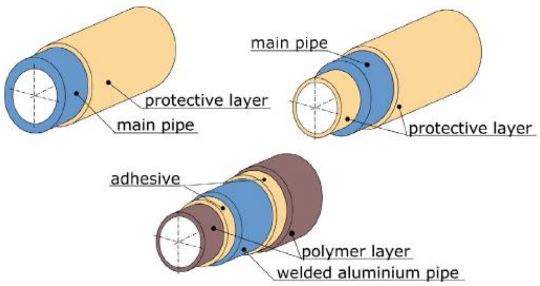

Fig.1 - Different examples of multilayered composite pipe systems used in practice

The modelling and analysis of multilayered composite pipe is a challenging problem. For the complete and accurate analysis of multilayered composite pipe, it is very necessary to recognise and utilize the factors which are imperative to design modelling. The proposed work includes analysis of the displacement and stress distribution of the multilayered composite pipes under internal pressure using finite element methodology and the study on finding alternative multilayered composite pipe for the given application from the point view of enhancing the strength to weight ratio.

B. Advantages Of Multilayered Composite Pipe

Composite systems are widely used in piping industries. The composite pipelines have the advantages of both metal and plastic, such as good mechanical properties of metal and good chemical properties of plastic. Therefore the composite pipelines are widely used in the areas such as water supply, heat supply, chemical industries, petroleum and natural gas transportation etc.

The properties of composites make them ideal in the oxidizing or reducing atmospheres generally found in these industries. Under the most corrosive environment, the life of metal pipe can only be measured in a few years (approximately 10 years), while the life of multilayered composite pipe is about 50 years. Homogeneous (one layer) plastic pipes can be destroyed by brittle fracture. A more effective solution is the use of multilayered composite pipe.

Composites also have higher strength to weight ratios compared to traditional engineering materials. Their low weight can help reduce installation and repair costs. Another important advantage of composites is the designer’s ability to tailor the material properties for a specific application

C. Applications Of Multilayered Composite Pipe

Multilayered composite pipes are mainly used for water and gas supply [14]. It is also used for various applications such as compressed air systems, natural gas distribution, submersible pump piping, jet pump piping, fuel oil lines, vacuum systems, food/chemical processing, refrigerant systems, air conditioning, solar heating, under floor heating, radiator central heating system etc.

II. FINITE ELEMENT ANALYSIS OF MULTILAYERED COMPOSITE PIPE

A. Introduction

The Finite Element Method is a numerical analysis technique used to obtain solutions that are associated with physical and non-physical problems of multilayered composite pipe. The underlying premise of the method states that a complicated domain can be sub-divided into a series of smaller regions in which the differential equations are approximately solved. By assembling the set of equations for each region, the behaviour over the entire domain is determined. Each region is referred to as an ‘element’ and the process of subdividing a domain into a finite numbers of elements is referred to as ‘discretization’. Elements are connected at specific points, called ‘nodes’ and the assembly process requires that the solutions be ‘continuous’ along common boundaries of adjacent elements.

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Linear commercial FE code ANSYS 16.0 is used to simulate structural analysis of multilayered composite pipes. The design model of the pipe is established in accordance with IS standards. The materials for the different layers of the pipe are selected from literature review. By using FEA the strain, stress generated in the pipe due to internal pressure is measured.

B. Model Development, Contact Conditions And Meshing

The geometry of the system is divided into a finite number of regions (elements), taking into account in shape, any symmetry, difference in material properties, loading points and boundary conditions. Meshing option helps to select number of elements in which model is to be subdivided and selection of meshing type depending upon accuracy required.

1) *Model development:* The basic FEA model for the multilayered composite pipe is developed in ANSYS workbench 16.0 as shown in fig.2 & fig.3 and then analysed it. The global coordinate system is used in analysis. The dimensions of the model are selected as per ISO 21003:2008 – Multilayered piping systems for hot and cool water.

Multilayered composite pipe of size 5063
Outside diameter – 63 mm
Wall thickness - 6.5 mm
Inside diameter – 50 mm
Middle Aluminium (Al) layer thickness - 0.5 mm
Inner layer thickness - 3 mm
Outer layer thickness - 3 mm

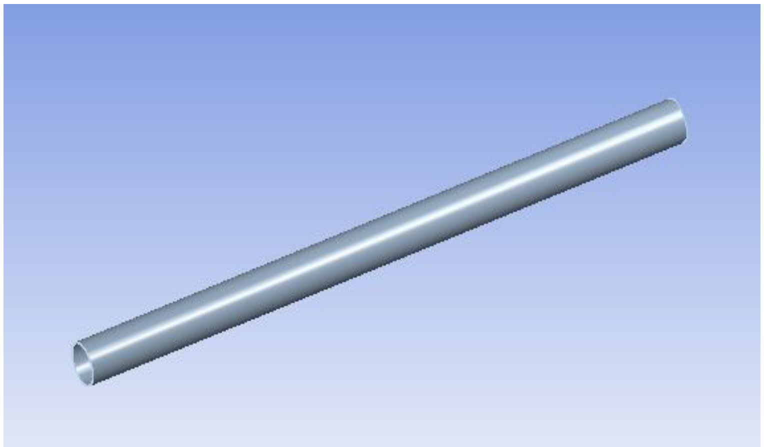

Fig.2 - The basic FEA model for the multilayered composite pipe

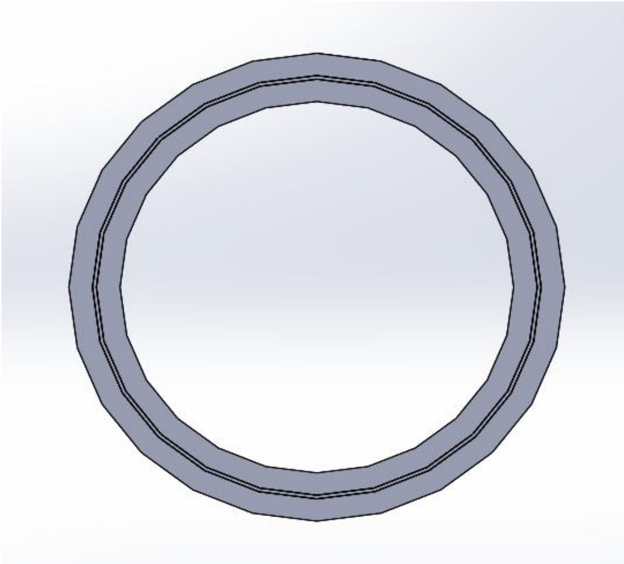

Fig.3 - The basic FEA model for the multilayered composite pipe

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TABLE I
Material properties of multilayered composite (MLC) pipe for structural analysis

Model	Layer	Material	Modulus of elasticity (E) MPa	Poisson's ratio
MLC pipe (PE-AL-PE)	Outer layer	Polyethylene	1213	0.35
	Middle layer	Aluminium	71000	0.33
	Inner layer	Polyethylene	1213	0.35

2) *Contact conditions:* When the surfaces of two different bodies touch each other in such a way that they become mutually tangent then it is said to be in contact. If surfaces that are in contact, they can transmit compressive normal forces and tangential friction forces and do not transmit tensile normal forces. The surfaces in contact are free to separate and move away from each other. The stiffness of the system depends on the contact status, whether parts is touching or separated. When forces which can be minimized by giving proper formulation of solver and appropriate contact type between connections of bodies. Contact conditions for multilayered composite pipe PE-AL-PE are as shown in table II

TABLE III
Contact conditions for multilayered composite pipe

Sr no.	Contact	Target	Type of interaction
1	Outer Polyethylene layer	Middle Aluminium layer	Bonded contact
2	Middle Aluminium layer	Inner Polyethylene layer	Bonded contact

3) *Meshing:* Formulation of elements in finite element analysis an important factor that can influence the simulation results considerably. Multilayered composite pipe PE-AL-PE is meshed using quad/ tri mesh type having mesh size 6.0 mm with fine relevance as shown in fig. 2.3 and fig. 2.4. This finite element model mesh has 795441 total nodes and 399182 total elements.

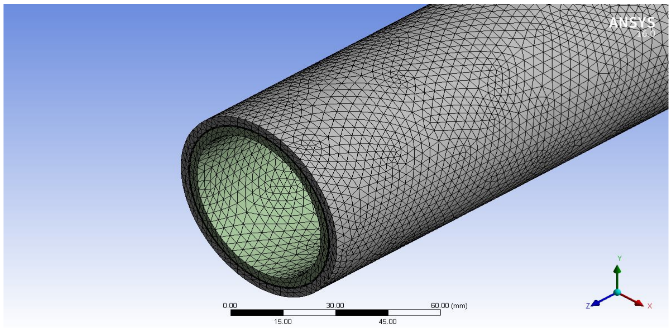

Fig.4 - Meshing of multilayered composite pipe

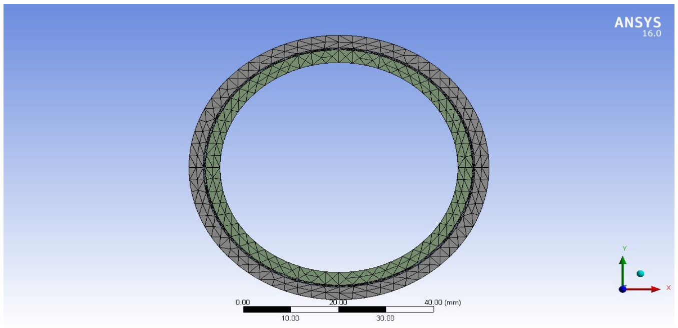

Fig.5 - Meshing of multilayered composite pipe

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C. Boundary And Loading Conditions

1) *Boundary Conditions:* The boundary conditions defined on the model should realistically reflect the loading conditions on the structure. The pipe is fixed on the both sides with end caps. So to constrain the displacement on the both sides of pipe, the Z – component of the coordinate system is ramped i.e. applied 0.0 mm as shown in fig.6. As the pipe is free to deflect in X & Y- components of the coordinate system, so the displacement in that direction is applied as free.
2) *Loading Conditions:* The pressure is applied on the inner surface of the pipe model as shown in fig.7. The working range of the pressure for multilayered composite pipe is up to 10 bar i.e. 1 Mpa, so the maximum internal pressure applied is 1 Mpa.

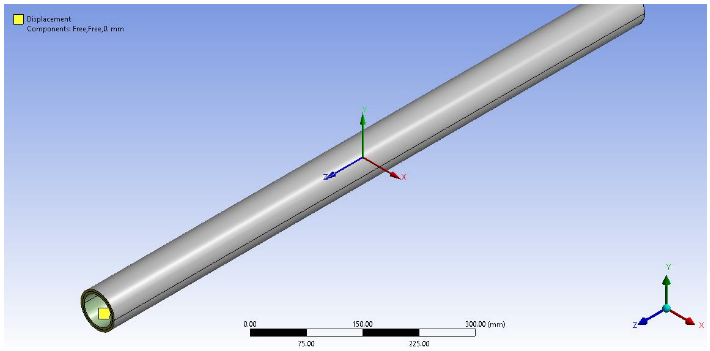

Fig.6 – Displacement components of the model

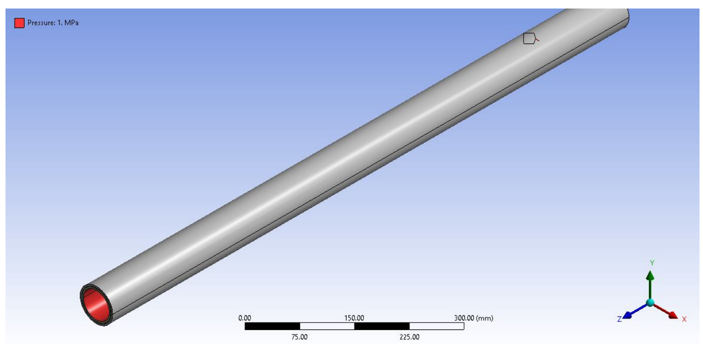

Fig.7 – Internal pressure applied on the model

III. SOLUTION AND RESULTS OF FINITE ELEMENT ANALYSIS FOR MULTILAYERED COMPOSITE PIPE

Finite element analysis result values of equivalent stress, equivalent strain and total deformation for multilayered composite pipe Polyethylene-Aluminium-Polyethylene (PE-AL-PE) are as shown in fig.8, fig.9, fig.10 respectively. And the results are tabulated in the table III.

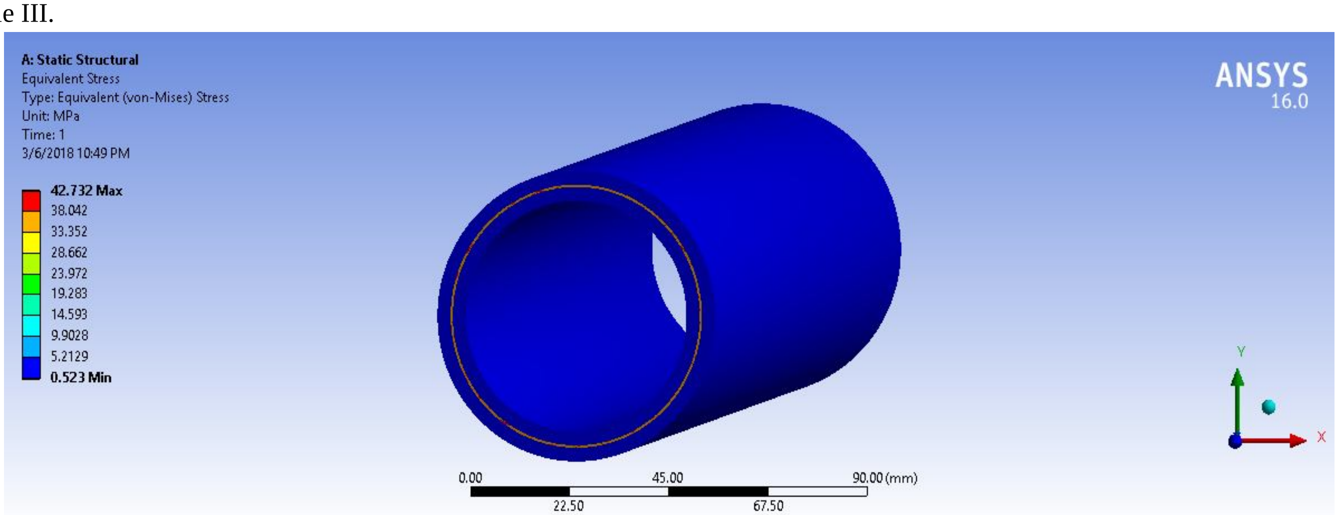

Fig.8 – Simulation of FEA results for multilayered composite pipe PE-AL-PE

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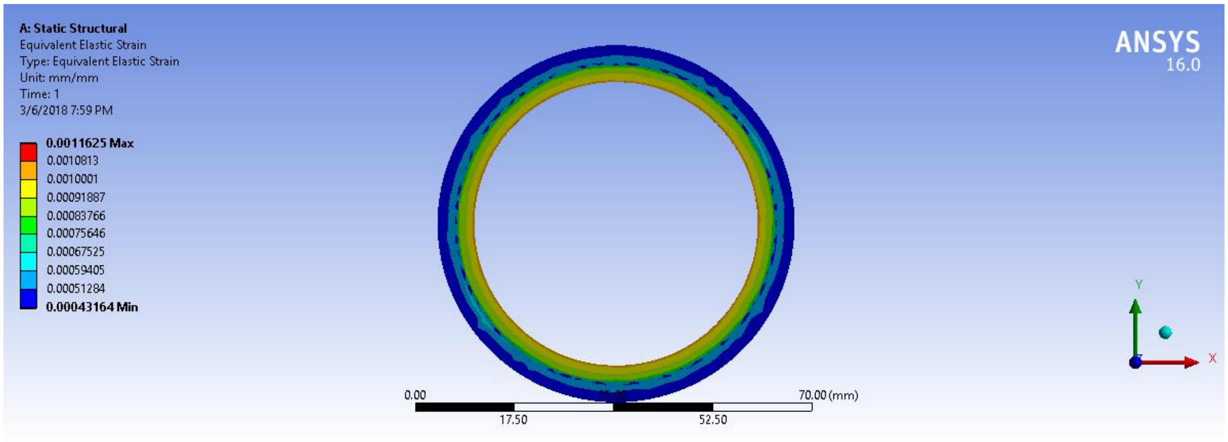

Fig.9 – Simulation of FEA results for multilayered composite pipe PE-AL-PE

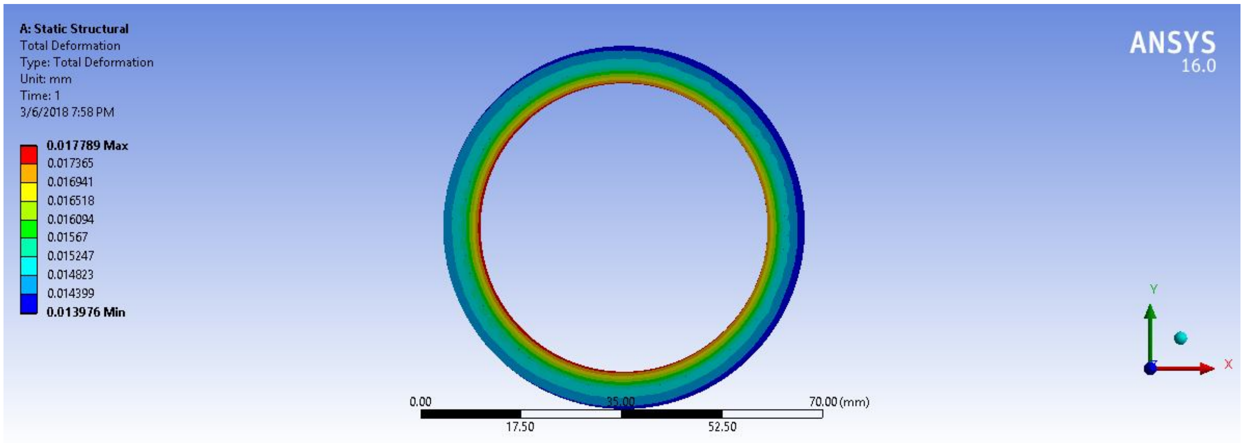

Fig.10 – Simulation of FEA results for multilayered composite pipe PE-AL-PE

TABLE III
FEA results for multilayered composite pipe PE-AL-PE

Equivalent Stress (maximum) Mpa	Equivalent Stress (minimum) Mpa	Equivalent Strain (maximum) Mpa	Equivalent Strain (minimum) Mpa	Total Deformation (maximum) mm	Total Deformation (minimum) mm
42.7320	0.52300	0.0011625	0.0004316	0.017789	0.013976

IV. CONCLUSIONS

The multilayered composite pipe PE-AL-PE is analyzed for equivalent stress, equivalent strain and total deformation. The working pressure range for low pressure gas and water systems is up to 10 bar (1 Mpa), and the FEA results obtained of MLC pipe for that pressure range are very good. So the more effective solution for the low pressure gas or liquid pipeline is the use of multilayered composite pipe. The conventional pipe for carrying fluids at low pressure is typically made of metal or plastic. The weight of the metal pipe for long and complex piping system becomes a matter of concern and the plastic pipes can be destroyed by brittle fracture. So the strength to weight ratio is not favorable for applications demanding low weight in case of metal pipe and for applications demanding high strength for low pressure systems in case of plastic pipe.

Multilayered composite pipes have higher strength to weight ratios compared to traditional engineering materials. Their low weight can help reduce installation and repair costs. The composite pipelines have the advantages of both metal and plastic, such as good mechanical properties of metal and good chemical properties of plastic.

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V. ACKNOWLEDGMENT

There are countless individuals that deserve my sincere gratitude for helping me to complete this study. First and foremost, I would like to express my gratitude to Prof. S. M. Ingale for his valuable guidance and help. He has given me ample of freedom in this study and also provided the moral support at tough situations. Again I am very thankful to Prof. S. V. Dhanal for his suggestions, help, encouragement and constant support.

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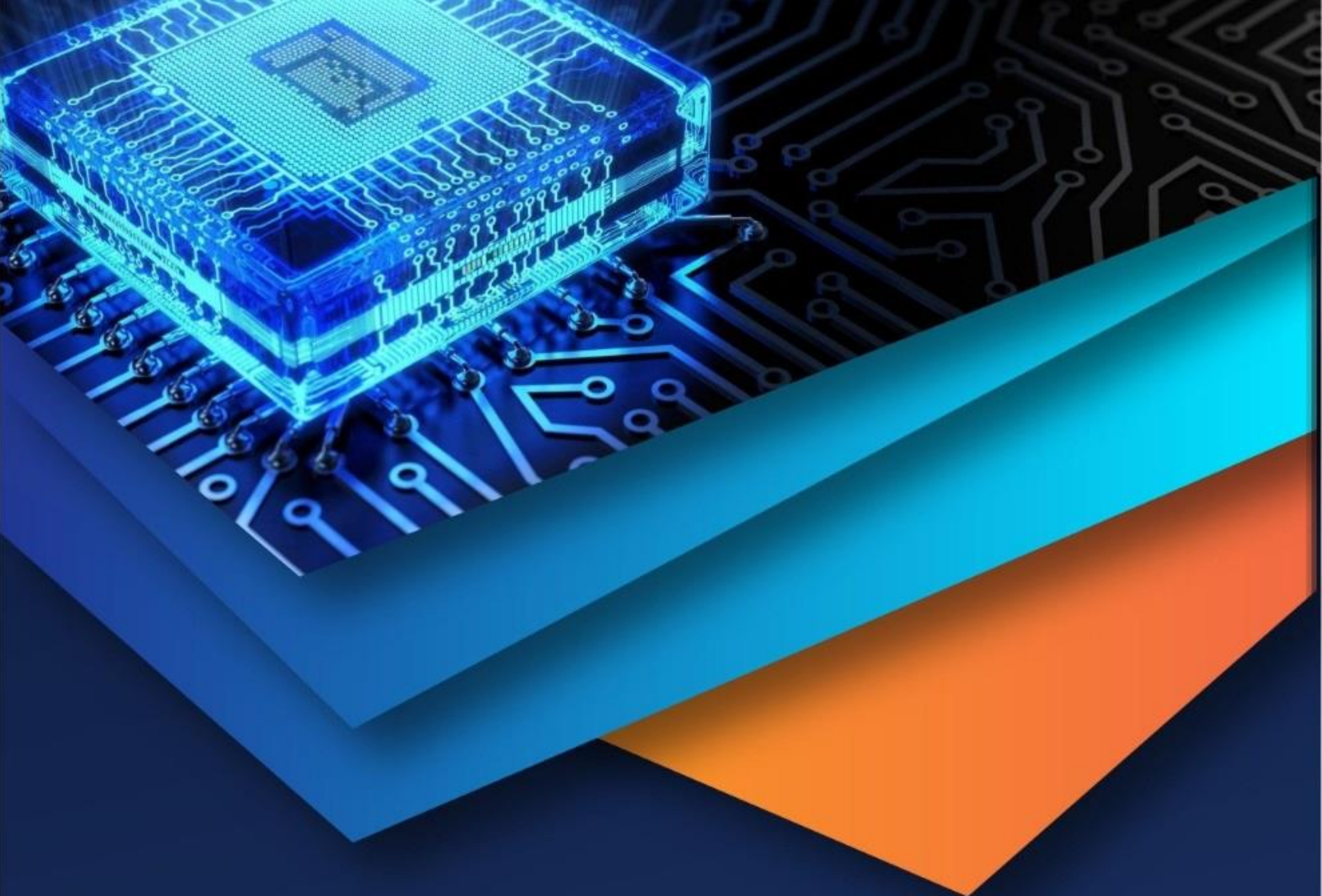

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